AUDITORY RESEARCH LABORATORY

1997

State University of New York at Plattsburgh
Plattsburgh, New York 12901

FINAL REPORT (Part 1)

Use of animal test data in the development of a human auditory hazard criterion for impulse noise

JAYCOR SUBCONTRACT AGREEMENT NO:
950342

ARL

JAYCOR

August 3, 2000

DTIC
Attn: Ms. Pat Mawby, DTIC/OCA
8725 John J. Kingman Rd – Suite 0944
Fort Belvoir, VA 22060-6218

RE: Documents to Include in DTIC Database

Dear Pat:

Enclosed are two documents that Dr. Philemon Chan of Jaycor would like to have available for public distribution through DTIC. There are no distribution limitations for either one.

Please note that Jaycor is moving to a new location August 11th. Our new address is:

Jaycor, Inc.
3394 Carmel Mountain Road
San Diego, CA 92121-1002

My new phone number will be (858) 720-4115. Please call if you have any questions.

Sincerely,

Brenda Ives

Brenda Ives
Group Support Specialist
Simulation, Engineering & Technology Group

Encls.

PS: Hope you're feeling much better!!

Plattsburgh
STATE UNIVERSITY OF NEW YORK

AUDITORY RESEARCH
LABORATORIES
Beaumont Hall -107

101 Broad Street
Plattsburgh NY 12901-2681
TEL (518) 564-7700
FAX (518) 564-7827

22 March 1999

J.M. Stuhmiller, Ph.D.
Fluid Dynamics Division
JAYCOR
P.O. Box 85154
San Diego, CA 92138

Dear Dr. Stuhmiller:

Enclosed are three errata sheets for the Final Report for JAYCOR Subcontract Agreement Number 950342, entitled "Use of animal test data in the development of a human auditory hazard criterion for impulse noise."

Sincerely,

William A. Ahroon, Ph.D.
Senior Research Scientist

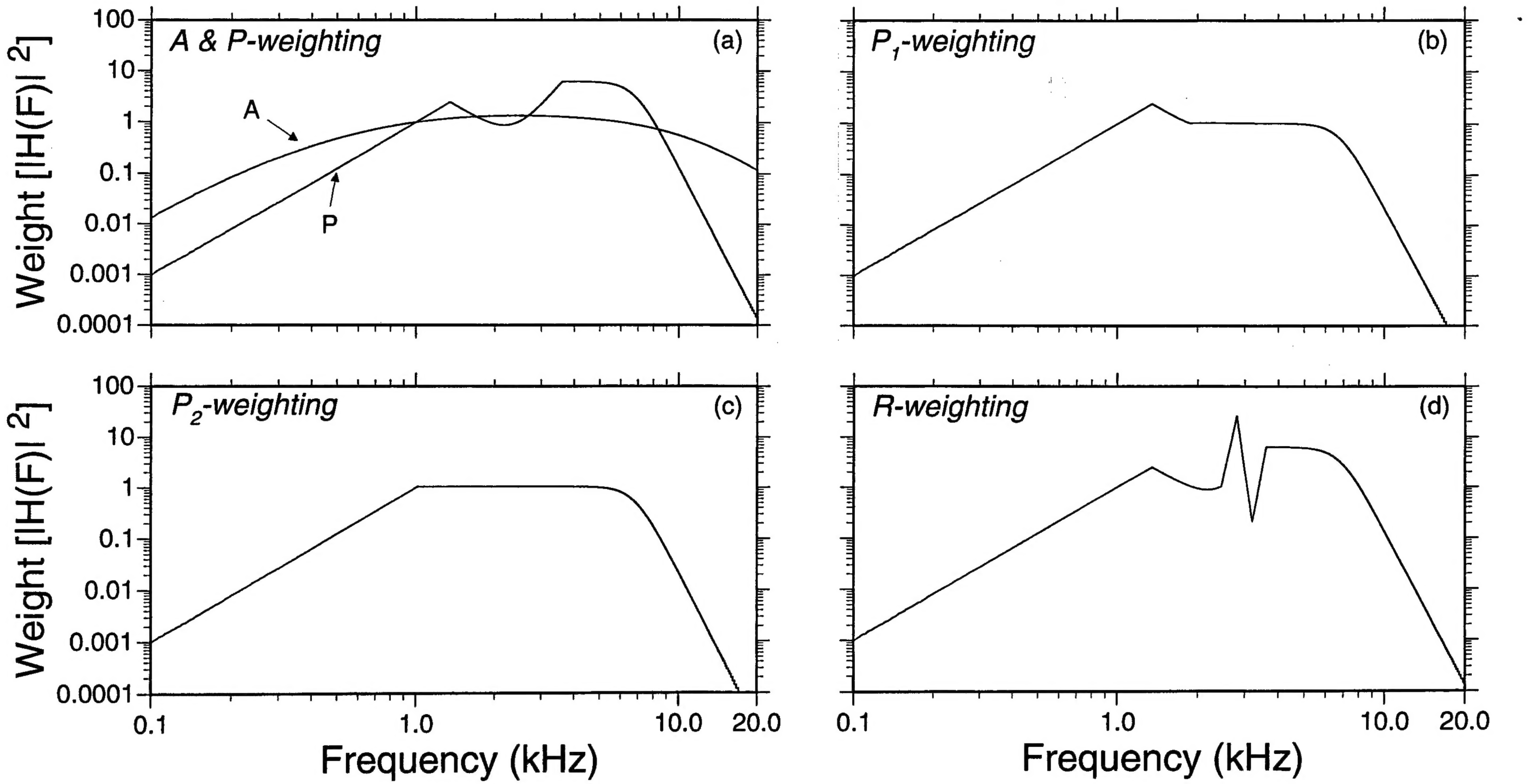


Figure 1. Graphical representation of the weighting functions used to compute some of the hazard indicies [Patterson et al. (1993)].

$$|H(F)|^2 = 2.45\left\{\left(\frac{F_1}{F}\right)^3 + 2.5\left(\frac{F}{F_2}\right)^6\right\}, \ for \ F_1 < F \leq F_2 \qquad \text{Eq. (6)}$$

$$|H(F)|^2 = 2.45\left\{\left(\left(\frac{F_1}{F_2}\right)^3 + 2.5\right)\left(\frac{\left[1+5(F_2/F_3)^{10}\right]}{\left[1+5(F/F_3)^{10}\right]}\right)\right\}, \ \text{for} \ F > F_2 \qquad \text{Eq. (7)}$$

where $F_1 = 1.35$ kHz, $F_2 = 3.6$ kHz, and $F_3 = 8.0$ kHz.

(7) P_1-weighted SEL (SEL_{P_1} in dB). This is the SEL computed from the energy spectrum of the impulse after it has been weighted by the P_1-weighting function defined in Eqs. 8-10. This spectral weighting function is shown in Figure 1(b).

$$|H(F)|^2 = 2.45\left\{\left(\frac{F}{F_1}\right)^3 + 2.5\left(\frac{F}{F_2}\right)^6\right\}, \ for \ F \leq F_1 \qquad \text{Eq. (8)}$$

$$|H(F)|^2 = 2.45\left\{\left(\frac{F_1}{F}\right)^3 + 2.5\left(\frac{F}{F_2}\right)^6\right\}, \ for \ F_1 < F \leq F_2' \qquad \text{Eq. (9)}$$

$$|H(F)|^2 = \frac{2.45}{6}\left\{\left(\left(\frac{F_1}{F_2}\right)^3 + 2.5\right)\left(\frac{\left[1+5(F_2/F_3)^{10}\right]}{\left[1+5(F/F_3)^{10}\right]}\right)\right\}, \ \text{for} \ F > F_2' \qquad \text{Eq. (10)}$$

where $F_1 = 1.35$ kHz, $F_2 = 3.6$ kHz, $F_2' = 1.9$ kHz, and $F_3 = 8.0$ kHz.

(8) P_2-weighted SEL (SEL_{P_2} in dB). This is the SEL computed from the energy spectrum of the impulse after it has been weighted by the P_2-weighting function defined by Eq. 11-12.

$$|H(F)|^2 = 2.45\left\{\left(\frac{F}{F_1}\right)^3 + 2.5\left(\frac{F}{F_2}\right)^6\right\}, \ for \ F \leq F_1' \qquad \text{Eq. (11)}$$

$$|H(F)|^2 = \frac{2.45}{6}\left\{\left(\left(\frac{F_1}{F_2}\right)^3 + 2.5\right)\left(\frac{\left[1+5(F_2/F_3)^{10}\right]}{\left[1+5(F/F_3)^{10}\right]}\right)\right\}, \ \text{for} \ F > F_1' \qquad \text{Eq. (12)}$$

where F_1 = 1.35 kHz, F_2 = 3.6 kHz, F_1' = 1.015 kHz, and F_3 = 8.0 kHz.

This spectral weighting function is shown in Figure 1(c).

(9) R-weighted SEL (SEL_R in dB). This is the SEL computed from the energy spectrum of the impulse after it has been weighted by the R-weighting function defined by Eqs. 13-19 :

$$|H(F)|^2 = 2.45\left\{\left(\frac{F}{F_1}\right)^3 + 2.5\left(\frac{F}{F_2}\right)^6\right\},\ for\ F \le F_1 \qquad \text{Eq. (13)}$$

$$|H(F)|^2 = 2.45\left\{\left(\frac{F_1}{F}\right)^3 + 2.5\left(\frac{F}{F_2}\right)^6\right\} 10^A,\ for\ F_1 < F \le F_2 \qquad \text{Eq. (14)}$$

$$|H(F)|^2 = 2.45\left\{\left(\left(\frac{F_1}{F_2}\right)^3 + 2.5\right)\left(\frac{\left[1 + 5(F_2/F_3)^{10}\right]}{\left[1 + 5(F/F_3)^{10}\right]}\right)\right\},\ \text{for}\ F > F_2 \qquad \text{Eq. (15)}$$

where F_1 = 1.35 kHz, F_2 = 3.6 kHz, F_3 = 8.0 kHz, and A is given in Equations 16-19.

$$A = 0,\ for\ F < 2.45\ and\ for\ F \ge 3.6 \qquad \text{Eq. (16)}$$

$$A = \left[(Log F - Log 2.45)\left(\frac{Log 4}{0.058}\right)\right],\ for\ 2.45 \le F < 2.8 \qquad \text{Eq. (17)}$$

$$A = \left\{\left[(Log 2.8 - Log F)\left(\frac{2 Log 4}{0.058}\right)\right] + Log 4\right\},\ for\ 2.8 \le F < 3.2 \qquad \text{Eq. (18)}$$

$$A = \left\{Log 0.25 - \left[(Log F - Log 3.2)\left(\frac{Log 0.25}{0.05115}\right)\right]\right\},\ for\ 3.2 \le F < 3.6 \qquad \text{Eq. (19)}$$

This spectral weighting function is shown in Figure 1(d).

The first three HIs are referred to in this report as 'peak' based indices. The P_1- and P_2-weighting functions are progressive simplifications of the P-weighting function. The R-weighting is an elaboration of the P-weighting function which makes it more similar to the energy transfer functions reported by Rosowski (1991). All of the HIs, except Peak SPL_B (MIL-STD-1474D), use an energy trading rule for number of impulses. The SEL HIs use a 10 Log N trading rule.

Plattsburgh
STATE UNIVERSITY OF NEW YORK

AUDITORY RESEARCH
LABORATORIES
Beaumont Hall -107

101 Broad Street
Plattsburgh NY 12901-2681
TEL (518) 564-7700
FAX (518) 564-7827

26 October 1998

J.M. Stuhmiller, Ph.D.
Fluid Dynamics Division
JAYCOR
P.O. Box 85154
San Diego, CA 92138

Dear Dr. Stuhmiller:

Enclosed are two errata sheets for the Final Report for JAYCOR Subcontract Agreement Number 950342, entitled "Use of animal test data in the development of a human auditory hazard criterion for impulse noise."

Sincerely,

William A. Ahroon, Ph.D.
Senior Research Scientist

Table 17. Nonlinear regression coefficients for Equation (20) and the coefficients of determination (r^2) for the regression of mean PTS measured at the 1, 2, and 4 kHz audiometric test frequencies on the nine hazard indices for subjects exposed to 10 (n=282) and 100 impulses (n=444).

90%ile

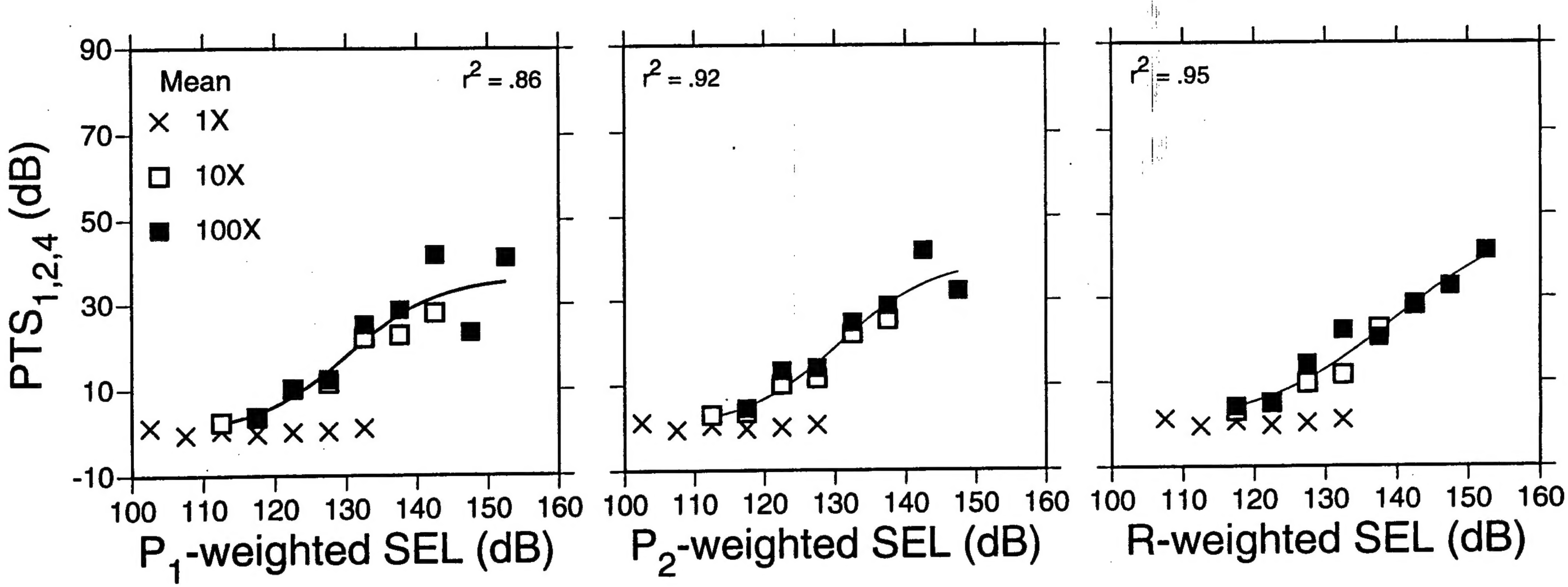
	C	B	A	r^2
Peak SPL_B	72.9	147.0	0.063	0.66
Peak SPL_C	40.2	123.4	0.246	0.43
Peak SPL_D	51.9	126.8	0.171	0.90
SEL_U	49.7	121.4	0.156	0.73
SEL_A	66.7	128.3	0.119	0.90
SEL_P	64.7	130.4	0.132	0.95
SEL_{P_1}	59.5	125.1	0.154	0.92
SEL_{P_2}	63.0	125.3	0.145	0.93
SEL_R	65.5	130.8	0.128	0.96

50%ile

	C	B	A	r^2
Peak SPL_B	855.9	208.6	0.071	0.62
Peak SPL_C	16.5	125.6	0.330	0.30
Peak SPL_D	16.3	129.6	0.181	0.47
SEL_U	59.8	154.4	0.057	0.35
SEL_A	39.8	135.0	0.162	0.79
SEL_P	78.5	147.0	0.113	0.95
SEL_{P_1}	42.4	132.9	0.185	0.77
SEL_{P_2}	43.5	132.1	0.232	0.89
SEL_R	84.7	148.5	0.110	0.94

Mean

	C	B	A	r^2
Peak SPL_B	200.8	201.6	0.045	0.64
Peak SPL_C	17.8	124.4	0.332	0.39
Peak SPL_D	20.6	127.0	0.188	0.70
SEL_U	25.3	125.2	0.120	0.55
SEL_A	38.3	132.7	0.130	0.90
SEL_P	47.1	138.4	0.114	0.96
SEL_{P_1}	36.3	130.2	0.155	0.86
SEL_{P_2}	39.7	130.7	0.148	0.92
SEL_R	49.6	139.7	0.108	0.95



(g) (h) (i)

Figure 68 (g-i) The mean average PTS measured at the 1, 2, and 4 kHz test frequencies for all animals exposed to 1, 10, or 100 impulses falling within 5 dB bins of the indicated level of the hazard index (g) P_1-weighted SEL, (h) P_2-weighted SEL, and (i) R-weighted SEL. The solid line is the nonlinear regression fit of Equation (20) to the 10X and 100X data. The three parameters, A, B, and C of Equation (20) corresponding to each regression line are listed in Table 17. (r^2 = coefficient of determination)

FINAL REPORT

Use of animal test data in the development of a human auditory hazard criterion for impulse noise

PREPARED BY:

Roger P. Hamernik
James H. Patterson, Jr.
William A. Ahroon

SUBCONTRACT AGREEMENT NO:
950342

PRIME CONTRACT NO:
DAMD17-96-C-6007

Jaycor PROJECT NO:
2997-28

SUBMITTED TO:

Jaycor
9775 Towne Centre Drive
San Diego, CA 92121

SUBMITTED BY:

State University of New York
812 Kehoe Building
101 Broad Street
Plattsburgh, NY 12901-2681

August 1998

TABLE OF CONTENTS

ABSTRACT

Hearing loss and sensory cell loss data, obtained from 909 chinchillas exposed to one of 137 different impulse noise or blast wave exposure paradigms, were statistically analyzed. The objective was to extract relations between the effects of the exposure on the auditory system (effects metrics) and metrics used to characterize the blast wave exposure. Specifically the following two questions were asked: (a) What is the best indicator of the amount of hazard associated with an impulse noise exposure? (b) How does the hazard of an impulse noise exposure accumulate with increasing numbers of impulses? Two analytical approaches were used. Both approaches indicated that the P-weighting functions or one of its derivatives (P_1-, P_2- or R-weighting) best organized the effects metrics. Depending on the analytical approach, either an energy trading rule of $10 \log_{10} N$ or $6 \log_{10} N$; where N is the number of impulses, best organized the data for N between 10 and 100. For exposures of between 1 and 10 impulses, a region of the parametric space that is of considerable practical significance, there is insufficient data to form any conclusions. For this region the limited data suggest that an energy trading rule i.e., $10 \log N$, does not work.

INTRODUCTION

This report represents the authors' response to Task 2 of Jaycor Project Number 2997-28; the analysis of animal data obtained from impulse noise/blast wave experiments performed at the US Army Aeromedical Research Laboratories (USAARL) and State University of New York, Auditory Research Laboratories (ARL) at Plattsburgh. Specifically these data were analyzed to determine what hazard index (measure of level and number trading rule) for exposure works best to predict injury.

The objective of Task 1 of this project was to collect all the appropriate animal (chinchilla) data from the above laboratory reports/records; transform them into a standard format and to annotate and store them in an easily accessible format so that future analyses can be performed. This task was completed and the data delivered on CD-ROM on 1 June 1998. Data taken from this CD-ROM were used to achieve the Task 2 objectives.

(1) Background: An understanding of how the various parameters of an impulse noise (blast wave) exposure affect hearing is critical to our abilities to evaluate noise exposures for: (a) design of safe and effective weapon systems, (b) design of hearing protective devices, and (c) hearing conservation purposes. Over the past fifteen years, the US Army Medical Research and Material Command (USAMRMC) has had an extensive program of research designed to develop new hazard assessment criteria for weapons blast overpressure. From the beginning this program focused on a number of fundamental issues:

a) What is the best indicator of auditory system hazard from exposure to impulsive noise? That is, which parameters or combination of parameters can be extracted from a blast wave pressure-time signature to best predict the auditory hazard of that impulse?
b) How does the spectrum of an impulse affect the hazard?
c) How does the maximum safe value of the hazard indicator (metric) change with exposure variables such as, for example, the number of impulses in an exposure, the interstimulus interval, or exposure environment (i.e., free field or reverberant)?

This USAMRMC program of experimentation included both human and animal components designed to determine the effects of exposure to blast overpressures and impulse noise on the auditory system. Due to the limitations on human research imposed by the need for safeguarding the health and safety of human volunteers, the human studies were restricted in scope. They included only four pressure-time signatures and involved only exposures with hearing protection (e.g., Patterson and Johnson, 1994a-c).

The animal studies, using the chinchilla as the experimental animal model, have been more extensive, involving 16 different pressure-time signatures, variations in the number of impulses from 1 to 100, and intensities from below the threshold of injury through to levels

that produced significant cochlear sensory cell loss and permanent hearing loss. Each study focused on a specific issue or set of issues. For example:

a) The number-intensity trading relation (Patterson et al., 1985; Hamernik et al., 1987)
b) The spectrum, number, intensity, and temporal spacing of impulses (Hamernik et al., 1988a, b, 1991a, b, c)
c) The development of an isohazard spectral weighting function (Patterson et al., 1993)
d) The effects of reverberation (Hamernik et al., 1995; Ahroon et al., 1996)
e) The effect of impulse peak versus energy (Patterson, 1991)

These studies, involving 909 subjects in 137 different exposure conditions, were performed either at the USAARL at Ft. Rucker, AL or at the Auditory Research Laboratories, State University of New York and University of Texas under the following grants/contracts; USAMRDC DAMD17-80-C-0133, USAMRDC DAMD17-83-G-9555 (Hamernik et al., 1988a), USAMRDC DAMD17-86-C-6172 (Hamernik et al., 1988b; 1990a, b, 1991a, 1991b), USAMRDC DAMD17-91-C-1113 (Hamernik et al., 1995), DAMD17-80-C-0109 (Patterson et al., 1985, 1986), DAMD17-86-C-6139, and DAMD17-91-C-1120. Taken together, this research generated a very large amount of data (probably the largest such data base currently in existence) on how the various parameters of a blast wave exposure contribute to both hearing loss and cochlear sensory cell loss.

To be effective, a damage risk criterion (DRC) for exposure to blast waves must be reasonably easy to interpret and apply. An essential first step in development of a DRC is to establish metrics for quantifying the exposure and the trauma, and to demonstrate that the metrics chosen are highly correlated with the indices of trauma.

Exposure to high levels of noise destroys or damages sensory cells which in turn causes an elevation of hearing thresholds and other auditory deficits. Immediately following an exposure, thresholds are shifted and over a period of several days a portion of this shift typically recovers. The shift that remains is considered the permanent threshold shift (PTS). Thus, our objective in this analysis was to find suitable metrics to describe the exposure and then to analyze statistically the relations among these metrics and the subsequent frequency-specific hearing loss and sensory cell loss.

Our data base on the auditory effects of blast wave exposure contains both the audiometric and quantitative histological (cochleograms) results along with a detailed analysis of each of the impulses. All the data from each exposure of each animal as well as the analysis of each waveform have been archived in computer files (Task 1) where they are readily accessible for analysis.

The fundamental question that the analysis will seek to answer is: How does PTS and sensory cell loss accumulate with increasingly severe exposures. Inherent in such a broadly-

stated question are the following two interrelated issues, each of which is addressed in the analysis:

(a) What is the best indicator of the amount of hazard associated with an impulse noise exposure? This question addresses the issue of the validity of an energy metric as an index of trauma. The energy of an exposure is increased by increasing the peak sound pressure level, the number of impulse presentations, and a change from a nonreverberant to a reverberant exposure environment. (Other variables such as repetition rate, which do not increase the exposure energy but are known to affect trauma, must also be considered, but are beyond the scope of this analysis.) While the total energy of an exposure stimulus can be the same for various sources, the distribution of energy across frequency can vary considerably for different blast waves. If different blast wave exposures are to be compared on a spectrally-weighted energy or pressure basis in order to estimate trauma, what is the most appropriate spectral-weighting function that should be applied to the spectrum of an impulse? For example, Patterson et al. (1993) have proposed the use of P-weighted energy as a basic hazard indicator. The P-weighting function was originally derived from a small subset of the data included in our database. However, it has not been evaluated in light of the entire database, particularly those data that were not used in its derivation. A suitable analysis would shed light on the generality of using the P-weighting function for assessing hazard. The analysis should also include an exploration of alternative spectral-weighting functions to determine whether there might be a better way of accounting for the spectral distribution of energy in an impulse. In addition to energy based metrics, 'peak' based indices of hazard such as those embodied in MIL-STD-1474D (Dept. of Defense, 1997), Smoorenburg (1982), or Pfander et al., (1980) need to be evaluated.

(b) How does the hazard of an impulse noise exposure accumulate with increasing numbers of impulses? A suitable analysis of the data base will also permit an evaluation of various schemes for assessing the increased hazard as number (N) of impulses is increased. While trauma may scale on a weighted-energy basis for a single impulse exposure, the accumulation of hazard with number of rounds may not follow a 10 log N rule implicit in an energy-based hazard indicator. Instead an X log N [e.g., the 5 log N in the DoD, MIL-STD-1474D (1997)] or perhaps a more complex formulation based on a fatigue equation (Oftedal, 1985) might better describe the data. As with spectral issues, other alternatives to an energy formulation must also be considered.

(2) Some methodological considerations: There were 137 different exposure conditions to which a total of 909 animals were exposed. The conditions of exposure and detailed experimental protocols used to acquire these animal data can be found in the references documented above as well as in the CD-ROM produced in Task 1. The Task 2 analyses used the permanent threshold shift and sensory cell loss data from all 909 chinchillas found on the Task 1 CD-ROM. Noise sources, exposure conditions and instrumentation systems differed between the USAARL and the ARL facilities. In the former, behavioral audiometry, using a shock avoidance procedure, was used to obtain pure-tone thresholds while in the latter,

auditory evoked potentials (AEP) recorded from the inferior colliculus were used. All animals were monaural. (That is, the left cochlea of each animal in the data base was surgically destroyed prior to any experimentation or audiometric testing.) All sensory sell loss data were obtained from conventional cochleograms (Engstrom et al., 1966) which were prepared for all animals at the ARL facility.

Conventional high intensity speakers were used to generate the low- and moderate-level impulse/impact stimuli while the high-level (>150 dB peak SPL) blast waves were generated by one of four different shock tubes or by a high energy spark discharge. These various sources allowed for control and variation of the peak sound pressure levels (SPL) and energy spectra of the exposure stimuli.

Each animal was individually exposed while restrained in a leather harness (Hargett et al., 1986). The configuration of the chinchilla's pinna during exposure differed at the two facilities. At the USAARL facility the chinchilla's pinna was stabilized with a wire loop in order to remove control of the pinna from the animal. The animal was exposed so that the plane containing the rim of the pinna was normal to the direction of travel of the advancing sound front. At the ARL facility the flap of the pinna was folded back and secured thus effectively reducing the influence of any pinna effect. The animal was exposed so that the plane of the entrance of the external meatus was normal to the direction of the advancing shock front.

ANALYTICAL METHODS

Two approaches were taken to the analysis of this database. The first method treats each animal individually without regard for the detailed conditions of exposure and seeks to: (1) determine the nature of the relation between various hazard indices (HI), defined below, and the measures of the effect of an exposure; PTS or sensory cell loss; (2) estimate the trading rule between number of impulses and their effect metrics. The second approach looks at the mean effects in groups of animals exposed to the same type of stimulus. This approach is designed to estimate which HI is the best predictor of effect. This approach is based on the fact that exposure to different stimulus types with the same value of the HI should produce the same effect. The degree to which the HI satisfies this condition will determine its suitability as a metric for estimating exposure effects. This was determined by estimating the value of each HI that produced a constant amount of effect for each stimulus type and examining the consistency of these HI values among the various stimulus types. This approach can also be used to estimate the trading rule for number of impulses by analyzing the data from different numbers of impulses separately. Each of these two approaches will be described separately.

Because of the large amount of variability in the injury process following a blast wave exposure it is not clear what the most appropriate single descriptor of trauma should be. The most typically employed single descriptive statistic has been the arithmetic mean,

representing the first moment of a distribution and a measure of central tendency. Considering the large variability in the effects produced by blast wave exposure, it may be appropriate to use the median as the measure of central tendency; a statistic based on the order of values of the dependent variables. However, a further argument can be made that a measure of central tendency does not effectively describe the hazard of an exposure since a damage risk criterion based on central tendency would only protect about half of the population. Since the goal of most exposure criteria is to protect a large percentage of the exposed population from injury it may be more appropriate to look, for example, at the most affected percentage of the population. Thus, a percentile-based measure (e.g., 90^{th} percentile) should be used if the objective is to protect a selected percentage of an exposed population. Thus, the analyses presented below will examine the effects of blast wave exposure on hearing using measures of central tendency and percentiles with both moment-based and order-based statistics.

Effect metrics:

(1) $PTS_{1,2,4}$: The PTS averaged across the 1, 2 and 4 kHz test frequencies was used as a measure of the audiometric effects (hearing loss) of an exposure with which HIs could be evaluated. These three frequencies were chosen because, based on the referenced literature and our experience with these exposures. These were the frequencies that typically showed the largest effects.

(2) Sensory cell loss: Three histological measures of injury were chosen for this analysis. Total outer or inner hair cell (OHC_T, IHC_T) loss, either in absolute numbers of cells lost or as a percent of the total cell population, was chosen as an index of permanent histological changes in the cochlea. Mean OHC and IHC population densities over the whole extent of the chinchilla cochlea or over consecutive octave band lengths of the cochlea are available from the literature (e.g., Hamernik et al., 1989; Bohne et al., 1982). The amount of cell loss occurring throughout the cochlea can be chosen to estimate the onset of noise-induced damage or, as with the PTS index, losses within the 1, 2 and 4 kHz octave band ($OHC_{1,2,4}$) can be used to evaluate the various HIs. (Inner hair cell loss is generally less diagnostic as an index of damage since IHC loss is not typically found until there is already a substantial OHC loss.)

Hazard indices:

In the following, Peak SPL (dB) is the highest SPL achieved during the time course of the impulse. As is customary, SPL implies a pressure reference, P_r = 20 μ Pascals (Pa). The following HIs were calculated for each exposure condition from data in the data base on the Task 1 CD-ROM.

(1) Peak SPL_D is the peak SPL adjusted by 10 log of the product of the D-duration (T_D) of the impulse as defined by Smoorenburg (1982) and the number of impulses. This value is defined by Eq. 1.

$$\text{Peak SPL}_D = \text{Peak SPL} + 10 \log\left[\left(T_D/T_r\right)\times N\right] \text{ (dB)} \qquad \text{Eq. (1)}$$

where $T_r = 1\text{s}$ and N = number of impulses.

(2) Peak SPL_C is the peak SPL adjusted by 10 log of the product of the C-duration (T_C) of the impulse as defined by Pfander (1980) and the number of impulses and is defined by Eq. 2.

$$\text{Peak SPL}_C = \text{Peak SPL} + 10 \log\left[\left(T_C/T_r\right)\times N\right] \text{ (dB)} \qquad \text{Eq. (2)}$$

where $T_r = 1\text{s}$ and N = number of impulses.

(3) Peak SPL_B is derived from the MIL-STD-1474D (1997) which incorporates the B-duration (T_B) of the impulse (Coles et al., 1968). Peak SPL_B is defined by Eq. 3.

$$\text{Peak SPL}_B = \text{Peak SPL} + 6.64 \log\left(T_B/T_r\right) + 5 \log N \text{ (dB)} \qquad \text{Eq. (3)}$$

where T_r = 200 ms and N = number of impulses.

(4) Unweighted sound exposure level (SEL_U in dB), where weighting refers to the frequency-specific attenuation or amplification imposed on the energy spectrum of the impulse and SEL is defined as:

$$\text{SEL} = 10 \log \int\left[P^2(t)/P_r^2 t_r\right]dt \qquad \text{Eq. (4)}$$

where t_r = 1s and P_r = 20 µPa. In this case, i.e., SEL_U, the weighting is a constant 0 dB attenuation.

(5) A-weighted SEL (SEL_A in dB). This is the SEL computed from the energy spectrum of the impulse after it has been weighted by the A-weighting function defined in ANSI S1.4 (1983). This spectral weighting function is shown in Figure 1(a).

(6) P-weighted SEL (SEL_P in dB). This is the SEL computed from the energy spectrum of the impulse after it has been weighted by the P-weighting function defined in Patterson et al. (1993). The equations that define this weighting function are Eqs. 5-7. This spectral weighting function is shown in Figure 1(a) where the A-weighting function is also plotted for comparison.

$$|H(F)|^2 = 2.45\left\{\left(\frac{F}{F_1}\right)^3 + 2.5\left(\frac{F}{F_2}\right)^6\right\},\ \textit{for}\ F \le F_1 \qquad \text{Eq. (5)}$$

$$|H(F)|^2 = 2.45\left\{\left(\frac{F_1}{F}\right)^3 + 2.5\left(\frac{F}{F_2}\right)^6\right\},\ for\ F_1 < F \le F_2 \qquad \text{Eq. (6)}$$

$$|H(F)|^2 = 2.45\left\{\left(\frac{F_1}{F_2}\right)^3 + 2.5\left(\frac{\left[1+5(F_2/F_3)^{10}\right]}{\left[1+5(F/F_3)^{10}\right]}\right)\right\},\ for\ F > F_2 \qquad \text{Eq. (7)}$$

where F_1 = 1.35 kHz, F_2 = 3.6 kHz, and F_3 = 8.0 kHz.

(7) P_1-weighted SEL (SEL_{P_1} in dB). This is the SEL computed from the energy spectrum of the impulse after it has been weighted by the P_1-weighting function defined in Eqs. 8-10. This spectral weighting function is shown in Figure 1(b).

$$|H(F)|^2 = 2.45\left\{\left(\frac{F}{F_1}\right)^3 + 2.5\left(\frac{F}{F_2}\right)^6\right\},\ for\ F \le F_1 \qquad \text{Eq. (8)}$$

$$|H(F)|^2 = 2.45\left\{\left(\frac{F_1}{F}\right)^3 + 2.5\left(\frac{F}{F_2}\right)^6\right\},\ for\ F_1 < F \le F_2' \qquad \text{Eq. (9)}$$

$$|H(F)|^2 = \frac{2.45}{6}\left\{\left(\frac{F_1}{F_2}\right)^3 + 2.5\left(\frac{\left[1+5(F_2/F_3)^{10}\right]}{\left[1+5(F/F_3)^{10}\right]}\right)\right\},\ for\ F > F_2' \qquad \text{Eq. (10)}$$

where F_1 = 1.35 kHz, F_2 = 3.6 kHz, F_2' = 1.9 kHz, and F_3 = 8.0 kHz.

(8) P_2-weighted SEL (SEL_{P_2} in dB). This is the SEL computed from the energy spectrum of the impulse after it has been weighted by the P_2-weighting function defined by Eq. 11-12.

$$|H(F)|^2 = 2.45\left\{\left(\frac{F}{F_1}\right)^3 + 2.5\left(\frac{F}{F_2}\right)^6\right\},\ for\ F \le F_1' \qquad \text{Eq. (11)}$$

$$|H(F)|^2 = \frac{2.45}{6}\left\{\left(\frac{F_1}{F_2}\right)^3 + 2.5\left(\frac{\left[1+5(F_2/F_3)^{10}\right]}{\left[1+5(F/F_3)^{10}\right]}\right)\right\},\ for\ F > F_1' \qquad \text{Eq. (12)}$$

where F_1 = 1.35 kHz, F_2 = 3.6 kHz, F_1' = 1.015 kHz, and F_3 = 8.0 kHz.

This spectral weighting function is shown in Figure 1(c).

(9) R-weighted SEL (SEL_R in dB). This is the SEL computed from the energy spectrum of the impulse after it has been weighted by the R-weighting function defined by Eqs. 13-19 :

$$|H(F)|^2 = 2.45\left\{\left(\frac{F}{F_1}\right)^3 + 2.5\left(\frac{F}{F_2}\right)^6\right\},\ for\ F \le F_1 \qquad \text{Eq. (13)}$$

$$|H(F)|^2 = 2.45\left\{\left(\frac{F_1}{F}\right)^3 + 2.5\left(\frac{F}{F_2}\right)^6\right\} 10^A,\ for\ F_1 < F \le F_2 \qquad \text{Eq. (14)}$$

$$|H(F)|^2 = \frac{2.45}{6}\left\{\left(\frac{F_1}{F_2}\right)^3 + 2.5\left(\frac{\left[1+5(F_2/F_3)^{10}\right]}{\left[1+5(F/F_3)^{10}\right]}\right)\right\},\ for\ F > F_2 \qquad \text{Eq. (15)}$$

where F_1 = 1.35 kHz, F_2 = 3.6 kHz, F_3 = 8.0 kHz, and A is given in Equations 16-19.

$$A = 0,\ for\ F < 2.45\ and\ for\ F \ge 3.6 \qquad \text{Eq. (16)}$$

$$A = \left[(LogF - Log2.45)\left(\frac{Log4}{0.058}\right)\right],\ for\ 2.45 \le F < 2.8 \qquad \text{Eq. (17)}$$

$$A = \left\{\left[(Log2.8 - LogF)\left(\frac{2Log4}{0.058}\right)\right] + Log4\right\},\ for\ 2.8 \le F < 3.2 \qquad \text{Eq. (18)}$$

$$A = \left\{Log0.25 - \left[(LogF - Log3.2)\left(\frac{Log0.25}{0.05115}\right)\right]\right\},\ for\ 3.2 \le F < 3.6 \qquad \text{Eq. (19)}$$

This spectral weighting function is shown in Figure 1(d).

The first three HIs are referred to in this report as 'peak' based indices. The P_1- and P_2-weighting functions are progressive simplifications of the P-weighting function. The R-weighting is an elaboration of the P-weighting function which makes it more similar to the energy transfer functions reported by Rosowski (1991). All of the HIs, except Peak SPL_B

(MIL-STD-1474D), use an energy trading rule for number of impulses. The SEL HIs use a 10 Log *N* trading rule.

Analytical approaches:

(1) The effect metrics ($PTS_{1,2,4}$, OHC_T and IHC_T losses, and $\%OHC_{1,2,4}$ losses) for each animal were plotted as scatter plots as a function of each of the nine HIs defined above. For each scatter plot the data set was then partitioned into 5 dB HI bins and the mean, 50th percentile and 90th percentile value of each effect metric lying in each bin was computed and displayed as a function of each HI. This manipulation of the data was performed in an effort to put some order into the data set and to establish some general relations among the dependent and independent variables. For each of these plots a nonlinear regression analysis was performed to find the best fit of a three parameter sigmoid function to the data. The sigmoid function was defined as:

$$\text{Effect metric} = C \Big/ 1 + e^{(B-HI)A} \qquad \text{Eq. (20)}$$

where A, B and C are parameters and HI is the hazard index (independent variable).

A similar organization of individual animal data along with a 5 dB bin reduction was performed on subsets of the data after grouping the animals with respect to the number of impulses they were subjected to; either 1, 10 or 100. A similar nonlinear regression analysis was performed on each of these subsets of the data.

(2) The second approach to the data analyses categorized the data according to the type of impulse, i.e., the wave shape as defined by the source that produced it. A nonlinear regression analysis was used to fit the same sigmoid function to the data for each type of impulse.

These analyses were done separately for the 10 and 100 impulse exposures in order to separate the contribution of the number-intensity trading rule from the basic HIs. After the nonlinear regression model had been fit to the data for a given number of impulses, the extent to which an HI organized the data, for that number of impulses, was determined. Then the parameters of the statistical model, estimated for a given number of impulses, were compared to those estimated for a different number of impulses in order to evaluate the number-intensity trading rule.

A nonlinear regression model was chosen because of the nature of the PTS and cell loss data as noted in earlier reports (Hamernik et al., 1989). The average PTS data are theoretically limited on the low side by 0 and appear to be limited at about 40 to 50 dB on the high side. Similarly, the percent cell loss data are limited by no loss on the low side and by 100% loss on the high side. Because of these limiting factors, a sigmoid shaped curve seemed to be a

reasonable choice as a function to use in the regression analysis. As in the first analysis the basic nonlinear regression model was:

$$\mathrm{PE}_i = C \Big/ 1 + e^{\left(B_i - HI_{ij}\right)A} \qquad \text{Eq. (21)}$$

Where PE_i is the predicted effect metric resulting from an exposure at a HI_{ij} level (dB). The subscript i denotes the type of impulse exposure stimulus. Each stimulus type was used at one to four different levels of the hazard indicator, indicated by the subscript j. The nonlinear regression model was fitted simultaneously to the data from all stimulus types for a given number of impulses. C, having units of the effect metric, is the asymptotic maximum value of the PE. C was first estimated for each HI using all exposure stimuli and then it was fixed for the final analyses. A (dB^{-1}) is the "slope" parameter that was also assumed to be the same for all stimuli. Forcing A and C to be the same for all stimuli ensures that the sigmoid curves for each stimulus type are "parallel". The B_is (dB) are offset parameters that are estimated from the regression analysis for each exposure stimulus type. The B_is are the value of the HI at the PE_i value of C/2. They represent a set of estimated iso-effect values of the HIs across the various stimuli, i.e., the B_is are the value of the HI for a constant PE. This model has the number of parameters equal to the number of different stimulus types plus 1 or 2 (depending on whether C is fixed). The values of A and C are interesting, but relatively unimportant for evaluating how well a HI organizes the data. The variability of the B_is is an indication of how well the HI has organized the data. If a hazard indicator accurately represents the hazard from a variety of stimuli, then the B_is should all be the same. The smaller the variance of the B_is, the better the HI organizes the data.

For the 100 impulse exposures, there were 15 different stimulus types defined in Table 21. Each combination of stimulus type, level, and number of impulses was given to a group of subjects. Two effect metrics were analyzed for the PTS data. The first was the mean $\mathrm{PTS}_{1,2,4}$ for each exposure combination. The second effect metric was the 90^{th} percentile value of $\mathrm{PTS}_{1,2,4}$ for each exposure combination. The 90^{th} percentile was estimated from the average and standard deviation across subjects in an exposure group using a t-distribution with *df* equal to one less than the number of subjects. The 100 impulse data were first analyzed with C as a free parameter for the average $\mathrm{PTS}_{1,2,4}$ and for the 90^{th} percentile $\mathrm{PTS}_{1,2,4}$. For the mean data, the value of C was approximately 50 dB for all HIs and approximately 70 dB for the 90^{th} percentile $\mathrm{PTS}_{1,2,4}$ for all HIs. These values were then fixed in the final analysis so that only 16 parameters were estimated.

The same basic analysis was repeated for the 10 impulse exposures. There were only 7 different stimulus types used in the 10 impulse exposures. One of the types (USAARL shock tube) that was included in this analysis used 12 impulses. For these analyses, the parameter C was not estimated from the data since few of the stimuli produced a maximal effect which was necessary to estimate C. Thus the value of C was fixed at 50 dB for the

average $PTS_{1,2,4}$ and at 70 dB for the 90^{th} percentile $PTS_{1,2,4}$. These values were derived from the 100 impulse estimates since the 100 impulse exposures tended to produce a maximal PTS.

These analyses were repeated for the 100 and the 10 impulse exposures using the percent OHC_T loss data and the percent $OHC_{1,2,4}$ as the effect metric. The value of the model parameter C was fixed at 100 percent and the value of A and the B_i's were estimated.

The single impulse exposures (1X) produced so little PTS and cell loss that it was not reasonable to attempt to fit the nonlinear regression model to the data.

RESULTS

Analytical approach (1): Figures 2 (a) through (i) show the scatter plots of the entire data base that relate the set of nine HIs to the dependent variable (effect metric) $PTS_{1,2,4}$. Note that the sample size in these figures is N=888 while the entire data pool contains an N=909. This difference in sample size is the result of some animals not having audiometric testing performed either as a result of the experimental design, equipment failure, or in a few cases because of errors in testing procedures.

Clearly seen in these figures, as well as in all the scatter plots of individual animal data that follow, is the almost chaotic relation between the individual animal response and the HIs. For the higher values of HI variability is extremely high; from some animals showing no effects to others that are severely damaged by the exposure. A second feature of the $PTS_{1,2,4}$ scatter plots is the generally triangular shape to the data space; there is a clear upper bound to the range of effects which monotonically increases with increasing HI. The results of the nonlinear regression using the sigmoid function is shown in each of these figures by the solid curve. The coefficients of determination (r^2) are, as expected, uniformly low. The parameters A, B, and C that define the sigmoid function and the r^2s are presented in Table 1.

When these $PTS_{1,2,4}$ data are organized into 5 dB bins an orderly relation between the dependent and independent variables emerges. This is shown in Figures 3 (a-i) through 5 (a-i) where the mean, 50th and 90th percentile values derived from the scatter plots are presented. The corresponding sigmoid parameters and the r^2s are presented in Table 1. While the generally high correlations for the three parameter sigmoid curve fit to this reduced data set are to be expected, there are small but systematic differences in the coefficient of determination, r^2; the weighted SEL HIs generally show the highest r^2 values, while the 'peak' based HIs show systematically lower r^2 values. For the $PTS_{1,2,4}$ data this is not a very strong effect. The high values of r^2 may be a simple reflection of the triangular shape of the scatter plot of the individual data which leads to monotonic increasing values of both the central tendency statistics and the 90^{th} percentile. These functions can be well fitted by the three parameter nonlinear regression equation. Even HIs that may not be particularly good indicators of hazard may appear to fit the data well.

Figures 6 through 17 show a parallel presentation of data for the sensory cell loss dependent variables; $\%OHC_{1,2,4}$, OHC_T and IHC_T. The corresponding sigmoid parameters and the r^2s are given in Tables 2-4. The scatter plots of these data will evoke similar impressions as were discussed above for the $PTS_{1,2,4}$ dependent variable, that is, there is considerable variability in the sensory cell loss for a given value of HI and there is a clear upper bound to the data space which is monotonically increasing. However the $OHC_{1,2,4}$ scatter plots show an interesting effect; the $OHC_{1,2,4}$ loss for the most affected animals shows a very rapid acceleration with increasing HI. Contrast, for example, the distribution of the $OHC_{1,2,4}$ loss in Figure 7 with the $PTS_{1,2,4}$ in Figure 3. This difference in the growth of these two effects metrics is emphasized in the 90%ile bin reduction of the data shown in Figures 3 and 7. Since the 1,2,4 kHz region of the cochlea is typically the first region to show the effects of excessive impulse noise exposure the different slopes of the $PTS_{1,2,4}$ and $\%OHC_{1,2,4}$ loss indicate that very small changes in $PTS_{1,2,4}$ measured in a subject can be associated with very large changes in the sensory cell population; certainly in the most susceptible segment of the exposed population. There are implications of this result for hearing conservation efforts especially if the damaged-ear hypothesis of Davis et al., (1950) has merit [see also Mills, (1992) and Humes, (1984)].

A comparison of corresponding plots of the OHC_T and IHC_T bin data in Figures 11 through 15 reinforces the observation that (1) there is an improved fit (higher r^2s) of the data for the weighted SEL HIs versus the peak based HIs, and (2) for any given value of HI, the OHCs are the more sensitive index of accumulating noise-induced pathology.

A set of figures whose format parallels those discussed above was obtained after the same data set was broken down by the number of impulse presentations (i.e., N = 1, 10, 100). The results of this analysis for N=1 are shown in Figures 18 through 33; the corresponding sigmoid parameters and the r^2s are given in Tables 5-8. The results for N=10 are shown in Figures 34 through 49; the corresponding sigmoid parameters and the r^2s are given in Tables 9-12. The results for N=100 are shown in Figures 50 through 65; the corresponding sigmoid parameters and the r^2s are given in Tables 13-16. The N=1 data are both interesting as well as straightforward. There was arguably, on average, essentially no effect on the auditory system from an exposure to a single impulse of the type used in these studies, that can be diagnosed by the chosen effects metrics. This is essentially the case across the entire range of HIs used in these experiments. It is only in the 90%ile, $PTS_{1,2,4}$ data (see e.g. Figure 19) that a small effect (< 10 dB) appears at the highest HI in the SEL_{P_1} and SEL_R plots. Since there is no measurable effect on the sensory cell population this 10 dB effect on $PTS_{1,2,4}$, if indeed it is a real effect, would suggest that the N=1 exposures, while not causing a loss of sensory cells, were responsible for cellular changes that altered their function. The best candidate for such noise-induced changes is a disturbance or loss of the stereocilia on a fairly large number of cells. Such stereocilia disturbances in the absence of sensory cell loss have been frequently documented in the literature.

More interesting, from a hearing conservation perspective, is a comparison of the N=1 exposures with the N=10 and N=100 data described below. The N=1 data show no effects at HI levels that are clearly damaging when the exposures consist of multiple impulse presentations at lower peak SPLs. This suggests that in the interval $1<N<10$ an energy trading rule (10 log N) does not work. Unfortunately there are no data available, either in the data base or in the literature, to resolve the nature of a trading rule in this region of the parameter space which is of considerable practical importance. This is a region of the parameter space in which animal data is needed before any predictive strategies can be developed or hazard assessments made.

The N=10 and N=100 data are consistent in showing systematically better r^2s for the P- and R-weighted SEL hazard indices. Also, a comparison of the $PTS_{1,2,4}$ data with the 90%ile $OHC_{1,2,4}$ data (e. g., Figures 35-37 and 39-41) further emphases the extremely rapid growth of the sensory cell lesion in the most susceptible population once a 'critical' HI level has been exceeded. The most significant aspect of this breakdown of the data set, however, is the fundamental support that the data provide for an energy-based trading rule for the number of impulse presentations. This is seen in Figures 66 through 77 where the data, reduced into bins, is replotted for the three Ns. A regression line using Eq. 20 was fit to only the N=10 and 100 data. The N=1 data were not included in this regression analysis for reasons that were discussed above. It is clear that, regardless of the effects metric used, there is a very good fit to the P- and R-weighted HIs, thus supporting an energy-based trading rule for the range $10 \leq N \leq 100$. The sigmoid parameters and the r^2s corresponding to Figures 66-70 are given in Tables 17-20.

<u>Analytical approach (2):</u> The group average $PTS_{1,2,4}$ and $\%OHC_T$ values as a function of the 9 HIs and the peak SPL, for the 100 impulse exposures are shown in Figures 78 and 79 (a through j). See Table 21 for stimulus/source identification. These figures, which represent a small subset of the data set, are included only in order to provide a visual impression of the organization of data by source/stimulus. Conclusions drawn from this second analytical approach are taken from the data presented in Tables 22 through 34. In general Figures 78 and 79 show that there is an orderly increase in the effects metrics for each stimulus type. There is considerable spread in the data along the HI axis from various stimuli in the three 'peak' based HIs and the unweighted energy graphs. This spread is reduced somewhat in the weighted SEL graphs. These figures also illustrate a consistent difference between the data from SUNY and the data from USAARL. The SUNY data tend to be to the right of the data from USAARL. The initial implication is that the stimuli used at SUNY are less hazardous than the USAARL stimuli for the same values of the HIs. The most likely explanation for this result is in the differences in the exposure methods used at the two laboratories. At USAARL, the pinna was constrained to be in an upright state and oriented toward the impulse source. At SUNY, the pinna was controlled by folding it back, simulating an animal without a pinna. Von Bismarck (1967) showed that removing the pinna from chinchillas resulted in reduction of energy transferred to the middle ear. This reduction was between 10 and 15 dB from 2 kHz to 10 kHz. All of the SUNY stimuli had considerable energy in this

frequency range. In addition to the pinna difference, there was a difference between the two laboratories in the way the animal was oriented with respect to the sound source, i.e., in the angle of incidence of the sound source to the ear. This angle was also shown by von Bismarck (1967) to affect the energy reaching the middle ear by 2-3 dB. Based on these estimates of the differences between the two methods, the SUNY data were shifted 10 dB to the left (more hazardous) and the $PTS_{1,2,4}$ and $\%OHC_T$ effects were plotted again in Figures 80 and 81 (a) through (j). Clearly the spread of the data from the various stimuli is substantially reduced for all of the HIs. However the weighted energy based HIs still organize the data better than the 'peak' based and unweighted energy HIs.

The results of fitting the nonlinear regression model to the $PTS_{1,2,4}$ data is presented in Table 22. The preliminary analysis indicated that C was approximately 50 dB for all HIs. Therefore, the value of C was fixed at 50 dB for the $PTS_{1,2,4}$ data. The offset parameter values, B_is, for each stimulus type, and the average value and the variance of these B_is is shown in this table for each of the 9 HIs. The variance of these numbers is a measure of the spread in the data noted in Figures 78 (a) to (j) and serves to quantify the visual impression seen in the figures. In this table, the average and variance of the SUNY stimuli and the USAARL stimuli are shown separately. These variances are typically smaller than the variances calculated for all 15 B_is. Finally, the average values and variances for all 15 stimuli are shown for the B_is with the SUNY data shifted 10 dB to the left [see also Figures 80 (a) to (j)]. There is a clear improvement in the variances for all HIs when the shifted data are used. The general trend for the weighted energy HIs to provide the best fit to the data is clear in all the variance values.

The other effect metrics from the 100 impulse exposures were analyzed in an analogous manner. Table 23 shows the B_is and their average and variance for the 90th percentile $PTS_{1,2,4}$. In this case the value of C was fixed at 70 dB based on the preliminary analyses. Tables 26 and 27 show the results of the nonlinear regression analysis of the average and 90th percentile using % OHC_T loss as the effects measure. Tables 30 and 31 show the results of the nonlinear regression analysis of the average and 90th percentile using % $OHC_{1,2,4}$ loss as the effects metric. The 90th percentile estimates for the % $OHC_{1,2,4}$ could not be fitted to the nonlinear regression model for several stimuli. This appears to be due to the large number of exposure conditions for which the 90th percentile loss estimates exceeded 100 percent as a result of the large differences among the individual subjects.

These analyses were repeated for the 10 impulse exposures. A set of results that parallel the above presentation are shown in Tables 24 and 25; 28 and 29; 32 and 33. The general trends for the weighted energy HIs to result in lower variances of the B_is seen in the 100 impulse data is clear in the 10 impulse data also. Generally the P-weighted SEL or the SEL using one of the variations on this weighting function have the lowest variances.

There were only a small number of exposures using 1 impulse and these generally led to no effects or very small effects. Therefore, no attempt was made to fit the nonlinear regression model to the 1 impulse data.

The number of impulses trading rule can be examined in this approach by comparing the average values of the B_is for the HIs with the lowest variances. If the trading rule implicit in the HIs is valid, there should be no difference in the averages values for the 100 impulse and the 10 impulse exposures. When this difference is not zero, it can be subtracted from the multiplier of log N to produce a new number trading rule. For example, the SEL measures use 10 log N as the trading rule; if the difference between the B_is for a 100 impulses and 10 impulses was 3 dB, this would indicate the trading rule is 7 log N.

Initially, the average B_is for the 10 impulse and the 100 impulse exposures shown in Tables 23 through 33 were used to calculate the differences in the B_is. The results showed considerable inconsistency across effects metrics. This was due to the fact that the slope parameter in the nonlinear regressions was estimated independently for the 10 impulse and the 100 impulse exposure conditions. In general, these estimates were not the same so the differences were based on the same estimated effects level from curves with different slopes. A more accurate evaluation of the number trading rule can be obtained by fitting the 10 impulse data nonlinear regression model in which both the slope and asymptote parameters (A and C) are fixed at the same values used for the 100 impulse data. These nonlinear regressions were only done for the weighted energy HIs since they showed the greatest consistency in the B_is across stimuli (smallest variances of the B_is). Table 34 shows the differences between the average B_is for the 10 impulses and the 100 impulses for the SUNY stimuli. These differences are probably the most valid comparison, since the exact same stimuli were used for both the 10 impulse and the 100 impulse exposures. For completeness, Table 34 also contains the differences based on all stimuli using the adjusted SUNY values. Overall, the differences in Table 34 are more consistent than those found in the initial analysis. The SUNY differences reflect a trading rule between 5 log N and 7 log N for all the effects measures. The adjusted averages are consistent with these values for the mean effects measures, but show a tendency toward larger differences in the 90th percentile effects measures. These estimates of the number trading rule only apply to exposures of 10 to 100 impulses since the 1 impulse data was not included in the analysis.

CONCLUSIONS

Analytical approach 1:

1. Weighted SEL HIs organize the data from the various exposure stimuli better than the peak based measures and unweighted energy.

2. The P-weighted, P_1-weighted, P_2-weighted, and R-weighted SEL fit better than the A-weighted SEL.

3. For the P-weighted, P_1-weighted, P_2-weighted, and R-weighted SEL HIs, the results were consistent with a number trading rule of 10 Log N for most of the effects measures for exposures of 10 to 100 impulses. Alternative trading rules were not explored. The 10 log N rule does not fit the 1 impulse exposure data.

Analytical approach 2:

1. Weighted SEL HIs organize the data from the various exposure stimuli better than the peak based measures and unweighted energy.

2. The P-weighted, P_1-weighted, P_2-weighted, and R-weighted SEL fit better than the A-weighted SEL.

3. For the P-weighted, P_1-weighted, P_2-weighted, and R-weighted SEL HIs, the number trading rule is close to 6 Log N for most of the effects measures for exposures of 10 to 100 impulses. Nothing can be concluded about the trading rule from 1 to 10 impulses.

REFERENCES

Ahroon, W.A., Hamernik R.P. and Lei, S-F. (1996) The effects of reverberant blast waves on the auditory system. J. Acoust. Soc. Am. 100:2247-2257.

Amercan National Standard Specification for Sound Level Meters, ANSI S1.4(1983), Standards Secretariat, Acoustical Society of America, New York, NY.

Bohne, B., Kenworthy, A. and Carr, C.D. (1982) Density of myelinated nerve fibers in the chinchilla cochlea. J. Acoust. Soc. Am. 72:102-107.

Coles, R.R.A., Garinther, G.R., Hodge, D.C. and Rice, C.G. (1968) Hazardous exposure to impulse noise. J. Acoust. Soc. Am. 43: 336-343.

Davis, H., Morgan, C.T., Hawkins, J.E. et al. (1950) Temporary deafness following exposure to loud tones and noise. Acta Otolaryngol. Suppl. 88:1-57.

Department of Defense, USA, (1997) Department of Defense design criteria standard, noise limits.

Engstrom, H., Ades, H.W., and Andersson, A. (1966) Structural pattern of the organ of Corti. Almqvist & Wiksell Pub. , Stockholm, Sweden.

Hamernik, R. P., Patterson, J. H., Jr., and Salvi, R. J. (1987) The effect of impulse intensity and the number of impulses on hearing and cochlear pathology in the chinchilla. J. Acoust. Soc. Am. 81: 1118-1129.

Hamernik, R.P., Ahroon, W.A., Davis, R.I., Hsueh, K.D. and Turrentine, G.A. (1988a) The Effects of Blast Trauma (Impulse Noise) on Hearing: A Parametric Study. Final Report for Grant DAMD17-83-G-9555 submitted to the U.S. Army Medical Research and Development Command. Report No. ARL 87-2. ADA Reference No. 206180.

Hamernik, R.P., Ahroon, W.A., Davis, R.I., Hsueh, K.D. and Turrentine, G.A. (1988b) The Effects of Blast Trauma (Impulse Noise) on Hearing: A Parametric Study. Annual Report No. I & II for Contract DAMD17-86-C-6172 submitted to the U.S. Army Medical Research and Development Command. Report No. ARL 88-2 and 88-3. ADA Reference No. 203854.

Hamernik, R.P., Patterson, J.H., Turrentine G.A. and Ahroon, W.A. (1989) The quantitative relation between sensory cell loss and hearing thresholds. Hear. Res. 38:199-212.

Hamernik. R.P., Ahroon, W.A., Davis, R.I., Hsueh, K.D. and Turrentine, G.A. (1990a) The Effects of Blast Trauma (Impulse Noise) on Hearing: A Parametric Study (Source II), Annual Report No. III for Contract DAMD17-86-C-6172 submitted to the U.S. Army Medical Research and Development Command. Report No. ARL 90-2. ADA Reference No. 221731.

Hamernik. R.P., Ahroon, W.A., Davis, R.I., Hsueh, K.D. and Turrentine, G.A. (1990b) The Effects of Blast Trauma (Impulse Noise) on Hearing: A Parametric Study (Source III), Annual Report No. IV for Contract DAMD17-86-C-6172 submitted to the U.S. Army Medical Research and Development Command. Report No. ARL 90-3. ADA Reference No. 228368.

Hamernik. R.P., Ahroon, W.A., Turrentine, G.A., Davis, R.I. and Lei, S.F. (1991a) The Effects of Blast Trauma (Impulse Noise) on Hearing: A Parametric Study (Source IV), Annual Report No. IV for Contract DAMD17-86-C-6172 submitted to the U.S. Army Medical Research and Development Command. Report No. ARL 91-1. ADA Reference No. 239643.

Hamernik. R.P., Ahroon, W.A., Turrentine, G.A., Davis, R.I., Hsueh, K.D. and Lei, S.F. (1991b) The Effects of Blast Trauma (Impulse Noise) on Hearing: A Parametric Study, Final Report for Contract DAMD17-86-C-6172 submitted to the U.S. Army Medical Research and Development Command. Report No. ARL 91-2. ADA Reference No. 241117.

Hamernik, R.P., Ahroon, W.A. and Hsueh, K.D. (1991c) The energy spectrum of an impulse: Its relation to hearing loss. J. Acoust. Soc. Am. 90:197-204.

Hamernik. R.P., Ahroon, W.A., and Lei, S.F. (1995) The Effects of Reverberant Blast Trauma (Impulse Noise) on Hearing: Parametric Studies. Final Report for Contract DAMD17-91-C-1113 submitted to the U.S. Army Medical Research and Development Command. Report No. ARL 95-1. ADA Reference No. 294548.

Hargett, C.E., Patterson, J.H., Jr., Curd, D.L., Carrier, M., Jr., Lomba-Gautier, I.M. and Jones, R.J. (1986) A chinchilla restraint system. USAARL Report No. 86-1.

Humes, L.E. (1984) Noise-induced hearing loss as influenced by other agents and by some physical characteristics of the individual. J. Acoust. Soc. Am. 76;1318-1329.

ISO-1999 (1990) Acoustics: Determination of occupational noise exposure and estimation of noise-induced impairment. (International Organization for Standardization, Geneva, Switzerland)

Mills, J.H. (1992) Noise-induced hearing loss: Effects of age and existing hearing loss. in *Noise-Induced Hearing Loss,* eds. A.L. Dancer, D. Henderson, R.J. Salvi and R.P. Hamernik. Mosby Year Book St. Louis, MO pp. 237-245.

Oftedal, G. (1985) Noise-induced Hearing Damage Caused by Metabolic Exhaustion: A Theoretical Study. The Norwegian Institute of Technology, Report No. STF44 -A85109

Patterson, J.H., Jr. (1991) Effects of peak pressure and energy of impulses. J. Acoust. Soc. Am. 90:205-208.

Patterson, J.H., Jr., Lomba-Gautier, I.M., Curd, D.L., Hamernik, R.P., Salvi, R.J., Hargett, C.E., Jr., and Turrentine, G. (1985) The effect of impulse intensity and the number of impulses on hearing and cochlear pathology in the chinchilla. USAARL Report No. 85-3.

Patterson, J.H., Jr., Lomba-Gautier, I.M., Curd, D.L., Hamernik, R. P., Salvi, R.J., Hargett, C.E., Jr., and Turrentine, G. (1986) The role of peak pressure in determining the auditory hazard of impulse noise. USAARL Report No. 86-7.

Patterson, J.H., Jr., Hamernik, R.P., Hargett, C.E. and Ahroon, W.A. (1993) An isohazard function for impulse noise. J. Acoust. Soc. Am. 93:2860-2869.

Patterson, J.H., Jr. and Johnson, D.L. (1994a) Direct determination of tolerance limits for intense freefield impulse noise when hearing protection is used. 18th Annual Meeting of the National Hearing Conservation Association, 17-19 Feb 1994, Atlanta, GA.

Patterson, J.H., Jr. and Johnson, D.L. (1994b) Temporary threshold shifts produced by high intensity freefield impulse noise in humans wearing hearing protection. Fifth International Symposium, Effects of Noise on Hearing, 12-14 May 1994, Gothenburg, Sweden.

Patterson, J.H., Jr. and Johnson, D.L. (1994c) Limits of exposure to high intensity impulse noise with a 1.5 ms A-duration. 127th Meeting of the Acoustical Society of America, 6-10 Jun 1994, Cambridge, MA.

Pfander, F., Bongartz, H., Brinkmann, H., and Kietz, H. (1980). Danger of auditory impairment from impulse noise: A comparative study of the CHABA damage-risk criteria and those of the Federal Republic of Germany. J. Acoust. Soc. Am. 67: 628-633.

Rosowski, J.J. (1991) The effects of external- and middle ear filtering on auditory threshold and noise-induced hearing loss. J. Acoust. Soc. Am. 90: 124-135.

Smoorenburg, G.F. (1982). Damage risk criteria for impulse noise. In: *New Perspectives on Noise-Induced Hearing Loss,* eds. R. P. Hamernik, D. Henderson, and R. J. Salvi, Raven Press, NY. pp. 471-490.

Von Bismarck, G. (1967) The sound pressure transformation from free-field to the eardrum of chinchilla. Master's Thesis, Massachusetts Institute of Technology.

Table 1. Nonlinear regression coefficients for Equation (20) and the coefficients of determination (r^2) for the regression of mean PTS measured at the 1, 2, and 4 kHz audiometric test frequencies on the nine hazard indices for all subjects (n=888).

	Scatter Graphs				90%ile			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	207.3	205.5	0.046	0.09	74.4	145.9	0.057	0.84
Peak SPL_C	22.3	128.8	0.205	0.16	43.1	124.5	0.281	0.72
Peak SPL_D	21.4	129.0	0.276	0.17	52.5	127.8	0.214	0.97
SEL_U	24.2	127.5	0.156	0.16	53.5	122.7	0.162	0.97
SEL_A	35.9	131.7	0.164	0.29	64.1	127.6	0.144	0.97
SEL_P	35.0	132.6	0.183	0.32	62.4	129.3	0.169	0.99
SEL_{P_1}	36.7	130.8	0.176	0.33	60.4	125.8	0.177	0.98
SEL_{P_2}	36.4	129.7	0.179	0.32	62.5	125.4	0.169	0.98
SEL_R	34.3	132.8	0.182	0.31	62.4	129.6	0.170	0.99

	50%ile				Mean			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	316.6	177.0	0.167	0.95	515.7	213.0	0.056	0.87
Peak SPL_C	15.2	129.8	0.177	0.56	18.2	126.3	0.309	0.67
Peak SPL_D	15.9	132.1	0.324	0.93	21.2	129.3	0.269	0.96
SEL_U	578.3	185.3	0.087	0.94	32.8	134.6	0.093	0.93
SEL_A	89.0	149.7	0.116	0.99	34.2	130.5	0.180	0.97
SEL_P	35.7	133.0	0.203	0.97	43.6	137.2	0.137	0.99
SEL_{P_1}	578.3	185.3	0.087	0.94	35.1	130.1	0.181	0.92
SEL_{P_2}	43.1	132.8	0.286	0.92	38.0	130.2	0.193	0.95
SEL_R	98.1	151.4	0.114	0.99	46.0	138.6	0.128	0.99

Table 2. Nonlinear regression coefficients for Equation (20) and the coefficients of determination (r^2) for the regression of mean percent OHC loss measured at octave-band lengths of the basilar membrane at the locations correlated with the 1, 2, and 4 kHz audiometric test frequencies on the nine hazard indices for all subjects (n=909). The value of C was set to 100 for these regressions.

	Scatter Graphs				90%ile			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	100.0	163.0	0.060	0.09	100.0	132.6	0.494	0.95
Peak SPL_C		147.9	0.064	0.13		125.5	0.615	0.74
Peak SPL_D		148.9	0.060	0.11		125.6	0.639	0.99
SEL_U		144.8	0.067	0.14		121.2	0.467	1.00
SEL_A		136.5	0.121	0.26		122.8	0.294	0.98
SEL_P		137.9	0.122	0.27		125.9	0.467	1.00
SEL_{P_1}		134.8	0.132	0.30		121.8	0.344	0.98
SEL_{P_2}		134.0	0.131	0.29		121.1	0.460	0.99
SEL_R		138.4	0.119	0.26		126.0	0.529	1.00

	50%ile				Mean			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	100.0	160.7	0.842	0.99	100.0	159.8	0.076	0.86
Peak SPL_C		162.2	0.067	0.47		155.5	0.055	0.52
Peak SPL_D		171.8	0.053	0.59		151.3	0.062	0.76
SEL_U		148.8	0.886	0.90		146.2	0.067	0.92
SEL_A		134.7	0.247	0.95		137.6	0.104	0.94
SEL_P		137.9	0.339	1.00		139.7	0.108	0.98
SEL_{P_1}		133.7	0.279	0.88		137.6	0.093	0.88
SEL_{P_2}		132.9	0.381	0.99		134.8	0.117	0.92
SEL_R		138.7	0.382	0.99		140.0	0.109	0.98

Table 3. Nonlinear regression coefficients for Equation (20) and the coefficients of determination (r^2) for the regression of total OHC loss on the nine hazard indices for all subjects (n=909).

	Scatter Graphs				90%ile			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	32200.8	206.0	0.054	0.12	5162.3	133.1	0.333	0.80
Peak SPL_C	2597.7	130.8	0.165	0.16	4598.9	126.3	0.355	0.65
Peak SPL_D	2305.6	129.8	0.264	0.17	6325.6	130.5	0.207	0.97
SEL_U	3002.6	131.0	0.124	0.16	5969.1	124.4	0.216	0.98
SEL_A	4443.9	134.1	0.150	0.31	6630.0	127.2	0.197	0.97
SEL_P	4359.7	135.2	0.157	0.32	6411.7	129.0	0.257	0.99
SEL_{P_1}	4327.0	132.3	0.170	0.35	6649.1	126.8	0.197	0.98
SEL_{P_2}	4313.3	131.4	0.169	0.34	6572.3	125.9	0.200	0.98
SEL_R	4272.7	135.4	0.155	0.31	6335.9	128.7	0.291	0.99

	50%ile				Mean			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	6530.6	162.6	0.474	0.98	62846.3	207.3	0.065	0.90
Peak SPL_C	17588.4	192.4	0.057	0.54	1986.1	127.2	0.250	0.60
Peak SPL_D	1542.3	134.3	0.172	0.97	2397.3	130.4	0.227	0.96
SEL_U	129380.7	169.7	0.188	0.94	9137.7	160.9	0.060	0.92
SEL_A	6966.0	140.8	0.159	0.97	4275.8	133.2	0.148	0.97
SEL_P	7014.4	143.1	0.186	1.00	5813.0	141.2	0.116	0.99
SEL_{P_1}	4615.4	134.5	0.215	0.81	4282.1	132.3	0.154	0.94
SEL_{P_2}	5544.6	135.4	0.236	0.98	4414.5	131.5	0.177	0.97
SEL_R	6830.9	142.9	0.202	1.00	6019.6	142.2	0.114	0.99

Table 4. Nonlinear regression coefficients for Equation (20) and the coefficients of determination (r^2) for the regression of total IHC loss on the nine hazard indices for all subjects (n=909).

	Scatter Graphs				90%ile			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	8877.9	205.7	0.084	0.10	21564.3	196.9	0.099	0.88
Peak SPL_C	2595.3	192.9	0.058	0.10	431.7	129.7	0.270	0.55
Peak SPL_D	152.4	130.9	0.297	0.09	529.2	132.9	0.406	0.94
SEL_U	2894.9	191.4	0.059	0.10	7629.2	191.1	0.057	0.84
SEL_A	5264.0	177.1	0.087	0.21	1131.2	139.9	0.121	0.94
SEL_P	1410.0	159.3	0.099	0.23	22639.1	187.6	0.083	0.98
SEL_{P_1}	902.1	150.8	0.103	0.23	3144.1	159.8	0.079	0.94
SEL_{P_2}	961.5	150.7	0.103	0.23	960.5	134.1	0.174	0.97
SEL_R	1798.7	163.7	0.094	0.22	26130.9	189.6	0.083	0.98

	50%ile				Mean			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	1070.6	167.5	0.513	0.99	6542.8	184.8	0.145	0.91
Peak SPL_C	1109.7	234.6	0.038	0.55	149.6	130.6	0.158	0.55
Peak SPL_D	38.2	127.9	0.219	0.86	164.4	131.9	0.251	0.90
SEL_U	1806.0	158.4	0.326	0.91	4986.7	191.2	0.071	0.82
SEL_A	3779.3	166.9	0.144	0.93	3407.4	173.3	0.084	0.97
SEL_P	4853.7	160.0	0.278	0.96	4333.7	173.8	0.097	0.98
SEL_{P_1}	5874.6	159.9	0.311	0.86	3742.8	177.6	0.078	0.90
SEL_{P_2}	310.5	141.1	0.179	0.98	470.4	138.9	0.138	0.99
SEL_R	4715.7	159.8	0.281	0.96	4371.1	173.4	0.099	0.98

Table 5. Nonlinear regression coefficients for Equation (20) and the coefficients of determination (r^2) for the regression of mean PTS measured at the 1, 2, and 4 kHz audiometric test frequencies on the nine hazard indices for subjects exposed to a single impulse (n=152).

	Scatter Graphs				90%ile			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	131.2	379.5	0.026	0.00	120.7	195.5	0.066	0.73
Peak SPL_C	90394.0	151.1	0.711	0.00	3179.8	362.6	0.028	0.91
Peak SPL_D	1083.0	143.1	1.049	0.00	5.8	114.0	0.143	0.92
SEL_U	0.7	128.7	10.711	0.01	95.4	232.2	0.028	0.65
SEL_A	47.2	140.9	0.351	0.01	119.9	207.8	0.037	0.71
SEL_P	277922500.0	259.9	0.154	0.01	1490.9	209.3	0.066	0.86
SEL_{P_1}	98.4	146.5	0.289	0.01	1531.9	232.8	0.051	0.85
SEL_{P_2}	116.0	145.0	0.298	0.01	72.5	189.9	0.038	0.75
SEL_R	244.1	151.5	0.282	0.01	1698.0	210.1	0.067	0.87

	50%ile				Mean			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	70.7	159.2	2.257	0.71	11.9	210.0	0.052	0.16
Peak SPL_C	0.6	-43295.0	0.000	0.60	1.2	112.0	-1.438	0.85
Peak SPL_D	-3.2	152.3	0.101	0.18	7.6	110.6	-1.150	0.78
SEL_U	3161.0	136.0	2.489	0.02	0.7	8941.8	0.000	0.13
SEL_A	24724.9	369.6	0.049	0.12	0.7	109.8	-0.053	0.09
SEL_P	5740007.0	152.4	0.757	0.66	51.8	142.7	0.384	0.41
SEL_{P_1}	23.2	559.5	0.008	0.00	207.4	153.2	0.257	0.20
SEL_{P_2}	1.2	187.5	-0.003	0.01	8.3	383.6	0.013	0.01
SEL_R	412572.8	138.8	1.986	0.25	291191.8	164.7	0.391	0.18

Table 6. Nonlinear regression coefficients for Equation (20) and the coefficients of determination (r^2) for the regression of mean percent OHC loss measured at octave-band lengths of the basilar membrane at the locations correlated with the 1, 2, and 4 kHz audiometric test frequencies on the nine hazard indices for subjects exposed to a single impulse (n=155). The value of C was set to 100 for these regressions.

	Scatter Graphs				90%ile			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	100.0	334.7	0.020	0.02	100.0	477.9	0.009	0.15
Peak SPL_C		255.4	0.028	0.01		533.0	0.007	0.06
Peak SPL_D		263.7	0.027	0.02		277.0	0.018	0.27
SEL_U		253.1	0.029	0.01		426.3	0.010	0.15
SEL_A		305.6	0.020	0.02		385.0	0.011	0.16
SEL_P		357.6	0.016	0.01		3872.2	0.001	0.09
SEL_{P_1}		376.1	0.014	0.01		312.0	0.015	0.19
SEL_{P_2}		362.7	0.015	0.01		640.5	0.006	0.03
SEL_R		371.8	0.015	0.01		288.6	0.017	0.33

	50%ile				Mean			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	100.0	1832.6	0.002	0.00	100.0	456.7	0.012	0.20
Peak SPL_C		2755.5	0.002	0.12		719.5	0.006	0.16
Peak SPL_D		2852.5	0.001	0.01		297.3	0.021	0.63
SEL_U		5489.4	0.001	0.00		491.0	0.010	0.24
SEL_A		8692.4	0.000	0.00		466.2	0.011	0.18
SEL_P		10034.9	0.000	0.02		4433.9	0.001	0.00
SEL_{P_1}		540.3	0.009	0.10		391.2	0.013	0.27
SEL_{P_2}		31274.0	0.000	0.00		465.7	0.011	0.12
SEL_R		394.8	0.015	0.22		349.5	0.016	0.37

Table 7. Nonlinear regression coefficients for Equation (20) and the coefficients of determination (r^2) for the regression of total OHC loss on the nine hazard indices for subjects exposed to a single impulse (n=155).

	Scatter Graphs				90%ile			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	1141.9	640.4	0.003	0.00	2128.9	595.9	0.004	0.01
Peak SPL_C	1142.5	312.9	0.009	0.01	30061.5	385.5	0.017	0.40
Peak SPL_D	2612.9	262.5	0.018	0.02	10062.3	229.9	0.030	0.48
SEL_U	843.1	319.8	0.006	0.00	6237.3	308.9	0.015	0.28
SEL_A	1006.7	293.3	0.008	0.00	8506.7	414.3	0.010	0.08
SEL_P	390.3	809.7	0.000	0.00	893.6	288.5	0.000	0.10
SEL_{P_1}	1101.2	652.7	0.003	0.00	3330.3	310.7	0.011	0.07
SEL_{P_2}	1047.8	643.9	0.003	0.00	2300.8	329.5	0.008	0.03
SEL_R	379.2	15549.7	0.000	0.00	1548.3	201.0	0.013	0.07

	50%ile				Mean			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	300.4	-414.2	0.000	0.42	376.0	2178.5	0.000	0.02
Peak SPL_C	870.7	47.7	-0.022	0.54	4885.8	2105.0	0.002	0.04
Peak SPL_D	703.5	563.2	0.003	0.01	2516.3	254.3	0.019	0.36
SEL_U	604.1	40.3	-0.014	0.30	1060.6	583.9	0.003	0.03
SEL_A	412.8	91.3	-0.018	0.27	1725.3	1076.5	0.002	0.01
SEL_P	1026.3	40.1	-0.021	0.58	443.2	1002.0	0.000	0.18
SEL_{P_1}	46839.3	147.5	0.371	0.00	976.8	320.9	0.007	0.04
SEL_{P_2}	21572.2	149.3	0.212	0.00	803.1	1550.8	0.001	0.00
SEL_R	13945.1	150.3	0.240	0.00	733.1	579.6	0.002	0.00

Table 8. Nonlinear regression coefficients for Equation (20) and the coefficients of determination (r^2) for the regression of total IHC loss on the nine hazard indices for subjects exposed to a single impulse (n=155).

	Scatter Graphs				90%ile			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	91.2	321.1	0.012	0.00	41.9	119.8	0.011	0.01
Peak SPL_C	227.8	295.5	0.018	0.01	221.1	324.9	0.010	0.07
Peak SPL_D	211.0	256.7	0.023	0.01	451.8	317.9	0.014	0.08
SEL_U	209.1	314.1	0.016	0.01	121.1	472.7	0.004	0.01
SEL_A	205.1	309.6	0.016	0.01	2274.0	151.8	0.167	0.00
SEL_P	21.0	964.7	0.000	0.00	52.3	26270.3	0.000	0.09
SEL_{P_1}	74.3	446.6	0.006	0.00	320.1	356.3	0.010	0.04
SEL_{P_2}	1805.0	376.5	0.020	0.00	47.1	1167.9	0.000	0.01
SEL_R	20.0	3771.8	0.000	0.00	119.6	758.1	0.002	0.00

	50%ile				Mean			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	76746.4	94.7	0.072	0.01	40.2	208.8	0.016	0.08
Peak SPL_C	5970.3	283.6	0.043	0.22	20.1	1612.7	0.000	0.00
Peak SPL_D	38.5	311.6	0.008	0.03	144.5	274.2	0.016	0.11
SEL_U	6543.1	277.0	0.045	0.01	101.2	406.8	0.008	0.04
SEL_A	288853.9	139.0	0.899	0.01	1345.3	150.5	0.191	0.02
SEL_P	3806.4	290.5	0.039	0.06	200.8	445.7	0.009	0.02
SEL_{P_1}	14.2	3453.2	0.000	0.02	152.3	353.0	0.011	0.04
SEL_{P_2}	720.6	709.4	0.008	0.14	47.5	501.6	0.003	0.01
SEL_R	14.7	633.5	0.000	0.01	139.4	326.0	0.012	0.07

Table 9. Nonlinear regression coefficients for Equation (20) and the coefficients of determination (r^2) for the regression of mean PTS measured at the 1, 2, and 4 kHz audiometric test frequencies on the nine hazard indices for subjects exposed to 10 impulses (n=282).

	Scatter Graphs				90%ile			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	184.0	193.4	0.063	0.13	76.7	156.2	0.074	0.89
Peak SPL_C	13.0	122.8	0.647	0.08	29.6	121.5	0.325	0.31
Peak SPL_D	12.7	123.2	0.717	0.07	40.7	124.3	0.225	0.90
SEL_U	415.2	218.7	0.041	0.07	34.3	117.7	0.312	0.60
SEL_A	258.1	165.3	0.082	0.21	87.0	136.6	0.077	0.81
SEL_P	73.3	145.9	0.103	0.22	61.1	130.5	0.123	0.92
SEL_{P_1}	46.9	136.9	0.108	0.23	51.9	122.8	0.161	0.89
SEL_{P_2}	55.0	138.6	0.103	0.23	54.7	123.8	0.157	0.87
SEL_R	137.5	156.9	0.090	0.21	64.9	132.0	0.116	0.93

	50%ile				Mean			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	735.0	191.9	0.114	0.64	180.9	189.9	0.067	0.81
Peak SPL_C	8.2	122.7	3.297	0.40	11.6	122.7	3.203	0.41
Peak SPL_D	57.8	195.7	0.036	0.47	13.3	123.1	0.264	0.78
SEL_U	2508.3	179.3	0.125	0.54	223.5	188.3	0.051	0.46
SEL_A	11116.3	158.9	0.279	0.89	1494.1	189.1	0.080	0.90
SEL_P	31.2	134.7	0.376	0.96	52.6	141.1	0.116	0.98
SEL_{P_1}	25.9	127.8	2.612	0.93	30.6	128.7	0.157	0.97
SEL_{P_2}	29.6	128.9	0.717	0.97	34.1	129.9	0.151	0.97
SEL_R	31.8	134.8	0.339	0.97	48.6	139.8	0.126	0.98

Table 10. Nonlinear regression coefficients for Equation (20) and the coefficients of determination (r^2) for the regression of mean percent OHC loss measured at octave-band lengths of the basilar membrane at the locations correlated with the 1, 2, and 4 kHz audiometric test frequencies on the nine hazard indices for subjects exposed to 10 impulses (n=284). The value of C was set to 100 for these regressions.

	Scatter Graphs				90%ile			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	100.0	161.9	0.087	0.13	100.0	143.3	0.333	0.93
Peak SPL_C		154.3	0.051	0.05		127.6	0.108	0.26
Peak SPL_D		169.5	0.030	0.02		124.7	0.889	0.98
SEL_U		149.7	0.057	0.07		119.2	0.892	0.61
SEL_A		135.8	0.130	0.20		119.4	0.776	0.96
SEL_P		137.2	0.137	0.21		124.1	0.567	0.97
SEL_{P_1}		135.0	0.123	0.23		119.6	0.733	0.98
SEL_{P_2}		134.0	0.126	0.22		119.5	0.725	0.98
SEL_R		138.0	0.131	0.20		124.5	0.493	0.98

	50%ile				Mean			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	100.0	160.8	0.923	0.71	100.0	159.6	0.102	0.74
Peak SPL_C		223.0	0.026	0.07		161.3	0.047	0.21
Peak SPL_D		159.4	0.109	0.71		151.6	0.066	0.60
SEL_U		141.2	0.864	0.85		145.9	0.070	0.43
SEL_A		136.3	0.903	0.98		136.5	0.124	0.83
SEL_P		137.4	0.391	0.98		137.6	0.142	0.97
SEL_{P_1}		134.5	0.215	0.94		135.1	0.116	0.95
SEL_{P_2}		132.9	0.324	0.97		133.5	0.140	0.97
SEL_R		137.4	0.390	0.98		137.7	0.150	0.98

Table 11. Nonlinear regression coefficients for Equation (20) and the coefficients of determination (r^2) for the regression of total OHC loss on the nine hazard indices for subjects exposed to 10 impulses (n=284).

	Scatter Graphs				90%ile			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	37199.3	195.4	0.078	0.17	32750.2	183.9	0.069	0.88
Peak SPL_C	106212.4	233.5	0.045	0.08	3069.0	122.7	6.093	0.49
Peak SPL_D	1277.9	123.1	0.830	0.07	3898.9	124.3	0.776	0.92
SEL_U	23350.7	189.4	0.051	0.09	68543.4	204.6	0.043	0.38
SEL_A	28092.0	161.1	0.096	0.25	8139.2	131.8	0.111	0.82
SEL_P	23745.9	159.8	0.101	0.26	16942.3	148.3	0.090	0.96
SEL_{P_1}	31406.2	165.5	0.086	0.28	7529.2	130.8	0.119	0.94
SEL_{P_2}	19865.3	156.7	0.092	0.27	6829.9	128.2	0.144	0.94
SEL_R	28451.5	162.8	0.098	0.25	11070.1	140.2	0.118	0.97

	50%ile				Mean			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	43436.1	170.7	0.299	0.75	38179.0	192.1	0.083	0.80
Peak SPL_C	604.6	122.7	3.094	0.36	1174.3	122.8	2.678	0.48
Peak SPL_D	428015.2	304.4	0.040	0.52	1301.9	123.4	1.179	0.93
SEL_U	5339637.0	162.2	0.382	0.80	42893.2	189.2	0.062	0.48
SEL_A	131197.8	152.6	0.375	0.92	43414.8	165.1	0.099	0.85
SEL_P	4981.8	138.9	0.251	0.99	47937.9	169.3	0.097	0.98
SEL_{P_1}	4908.5	137.1	0.154	0.95	4980.9	136.8	0.117	0.97
SEL_{P_2}	3416.7	131.2	0.312	0.98	6599.2	139.5	0.119	0.97
SEL_R	4986.9	138.9	0.251	0.99	22238.3	158.8	0.105	0.98

Table 12. Nonlinear regression coefficients for Equation (20) and the coefficients of determination (r^2) for the regression of total IHC loss on the nine hazard indices for subjects exposed to 10 impulses (n=284).

	Scatter Graphs				90%ile			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	10603.7	186.7	0.159	0.13	10472.3	186.5	0.124	0.82
Peak SPL_C	2003.4	192.0	0.060	0.05	2592.4	174.3	0.069	0.50
Peak SPL_D	66.0	122.8	0.831	0.03	192.9	124.6	0.387	0.85
SEL_U	2313.4	187.9	0.065	0.05	15770.5	188.1	0.081	0.37
SEL_A	11558.7	171.1	0.127	0.16	10971.6	158.1	0.150	0.88
SEL_P	56314.9	184.7	0.128	0.17	10634.6	161.4	0.155	0.92
SEL_{P_1}	9037.7	174.1	0.110	0.17	1756.0	149.1	0.114	0.96
SEL_{P_2}	9556.6	171.8	0.115	0.17	8197.2	157.2	0.141	0.92
SEL_R	10935.1	172.1	0.129	0.16	9569.1	159.6	0.165	0.94

	50%ile				Mean			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	597.4	164.3	0.478	0.95	3628.7	177.8	0.174	0.82
Peak SPL_C	17.3	114.4	0.256	0.08	396.6	172.9	0.048	0.33
Peak SPL_D	17.5	118.8	0.327	0.80	69.3	123.7	0.676	0.79
SEL_U	9008.1	158.0	0.295	0.82	5574.9	183.5	0.089	0.51
SEL_A	34027810.0	166.1	0.448	0.86	10412.5	167.8	0.136	0.76
SEL_P	47857.4	171.7	0.192	0.98	3033.0	157.6	0.162	0.94
SEL_{P_1}	1611.6	160.3	0.121	0.87	30705.0	185.8	0.112	0.95
SEL_{P_2}	93.9	129.2	1.119	0.95	22683.6	178.6	0.119	0.92
SEL_R	110707.4	175.7	0.194	0.98	40469.1	174.8	0.158	0.95

Table 13. Nonlinear regression coefficients for Equation (20) and the coefficients of determination (r^2) for the regression of mean PTS measured at the 1, 2, and 4 kHz audiometric test frequencies on the nine hazard indices for subjects exposed to 100 impulses (n=444).

	Scatter Graphs				90%ile			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	29.1	135.9	0.125	0.11	55.7	132.2	0.153	0.93
Peak SPL_C	25.1	127.7	0.339	0.11	45.5	123.8	0.278	0.54
Peak SPL_D	25.0	130.0	0.392	0.10	53.9	126.4	0.201	0.96
SEL_U	25.1	123.8	0.292	0.11	54.2	121.3	0.208	0.95
SEL_A	35.2	129.3	0.139	0.16	60.4	125.6	0.186	0.98
SEL_P	33.9	130.2	0.167	0.20	62.9	128.8	0.158	0.99
SEL_{P_1}	36.1	129.0	0.172	0.21	60.6	125.3	0.186	0.97
SEL_{P_2}	35.6	128.0	0.173	0.21	62.5	124.4	0.164	0.97
SEL_R	32.5	129.8	0.177	0.19	63.2	129.0	0.151	0.98

	50%ile				Mean			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	453.2	209.7	0.052	0.73	63.5	161.6	0.050	0.77
Peak SPL_C	21.8	126.6	0.323	0.40	21.7	125.2	0.323	0.48
Peak SPL_D	19.0	129.0	0.312	0.70	22.9	126.7	0.246	0.84
SEL_U	23.3	123.4	0.299	0.41	25.1	122.1	0.257	0.75
SEL_A	33.1	130.0	0.203	0.82	33.0	128.6	0.185	0.92
SEL_P	119.9	155.7	0.088	0.96	45.1	136.4	0.113	0.96
SEL_{P_1}	42.7	132.0	0.259	0.75	36.2	129.0	0.195	0.82
SEL_{P_2}	44.1	132.4	0.245	0.87	38.7	129.1	0.161	0.90
SEL_R	191.4	164.8	0.080	0.95	50.7	139.5	0.096	0.95

Table 14. Nonlinear regression coefficients for Equation (20) and the coefficients of determination (r^2) for the regression of mean percent OHC loss measured at octave-band lengths of the basilar membrane at the locations correlated with the 1, 2, and 4 kHz audiometric test frequencies on the nine hazard indices for subjects exposed to 100 impulses (n=444). The value of C was set to 100 for these regressions.

	Scatter Graphs				90%ile			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	100.0	153.4	0.050	0.10	100.0	132.0	0.519	0.93
Peak SPL_C		145.7	0.043	0.06		125.4	0.298	0.54
Peak SPL_D		147.6	0.038	0.04		124.6	0.268	0.99
SEL_U		142.5	0.045	0.07		120.2	0.298	0.99
SEL_A		136.3	0.095	0.16		123.4	0.340	0.99
SEL_P		137.6	0.097	0.18		126.4	0.443	1.00
SEL_{P_1}		134.3	0.117	0.22		123.1	0.379	0.99
SEL_{P_2}		133.6	0.114	0.21		121.5	0.506	1.00
SEL_R		138.1	0.094	0.17		126.3	0.450	1.00

	50%ile				Mean			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	100.0	150.5	0.092	0.54	100.0	153.0	0.058	0.64
Peak SPL_C		148.6	0.053	0.17		152.4	0.045	0.28
Peak SPL_D		160.6	0.044	0.20		149.6	0.054	0.60
SEL_U		160.5	0.038	0.10		143.8	0.052	0.58
SEL_A		134.4	0.201	0.80		137.4	0.099	0.84
SEL_P		136.9	0.216	0.94		139.2	0.101	0.93
SEL_{P_1}		131.4	0.402	0.83		136.4	0.094	0.76
SEL_{P_2}		132.8	0.352	0.99		134.3	0.107	0.86
SEL_R		138.2	0.222	0.86		139.5	0.099	0.92

Table 15. Nonlinear regression coefficients for Equation (20) and the coefficients of determination (r^2) for the regression of total OHC loss on the nine hazard indices for subjects exposed to 100 impulses (n=444).

	Scatter Graphs				90%ile			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	3762.5	142.1	0.087	0.13	5697.1	133.0	0.468	0.89
Peak SPL_C	2715.8	129.2	0.404	0.13	4846.5	126.2	0.341	0.51
Peak SPL_D	2706.3	131.5	0.549	0.13	6377.2	129.3	0.207	0.99
SEL_U	2720.2	125.4	0.332	0.13	6056.8	123.1	0.240	0.97
SEL_A	4216.7	132.0	0.138	0.20	6456.3	126.2	0.227	0.97
SEL_P	4071.6	132.7	0.151	0.22	6303.4	128.0	0.338	0.98
SEL_{P_1}	4026.3	130.2	0.192	0.26	6584.6	126.4	0.243	0.98
SEL_{P_2}	3993.6	129.3	0.186	0.24	6459.1	124.3	0.241	1.00
SEL_R	3815.0	132.0	0.161	0.21	6308.9	128.0	0.323	0.98

	50%ile				Mean			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	48552.3	203.6	0.059	0.69	23662.6	203.6	0.042	0.75
Peak SPL_C	48552.3	203.6	0.059	0.69	2345.3	127.0	0.343	0.50
Peak SPL_D	2024.0	131.7	0.396	0.68	2557.8	129.0	0.254	0.91
SEL_U	54163.1	206.1	0.048	0.37	2763.1	123.8	0.267	0.72
SEL_A	7868.6	142.6	0.129	0.87	3914.2	130.9	0.169	0.92
SEL_P	9297.9	147.6	0.127	0.95	5440.6	139.2	0.115	0.96
SEL_{P_1}	4435.0	132.6	0.266	0.74	4131.3	130.5	0.206	0.89
SEL_{P_2}	5694.3	135.4	0.209	0.98	4382.7	130.6	0.169	0.95
SEL_R	9900.4	148.7	0.124	0.95	6043.8	141.8	0.103	0.95

Table 16. Nonlinear regression coefficients for Equation (20) and the coefficients of determination (r^2) for the regression of total IHC loss on the nine hazard indices for subjects exposed to 100 impulses (n=444).

	Scatter Graphs				90%ile			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	1938.6	201.9	0.047	0.10	7054.3	203.5	0.049	0.82
Peak SPL_C	190.9	129.7	0.356	0.07	451.5	127.9	0.312	0.46
Peak SPL_D	186.5	131.6	0.527	0.07	547.4	131.7	0.276	0.90
SEL_U	189.9	125.9	0.299	0.07	601.1	126.0	0.181	0.69
SEL_A	3306.6	176.7	0.073	0.14	1186.4	140.5	0.106	0.91
SEL_P	13841.7	200.1	0.071	0.17	6339.0	173.0	0.074	0.93
SEL_{P_1}	4792.0	183.5	0.069	0.17	1572.9	144.1	0.097	0.90
SEL_{P_2}	5355.8	183.4	0.070	0.16	993.5	133.8	0.146	0.97
SEL_R	2586.3	174.1	0.074	0.16	32153.2	200.0	0.069	0.93

	50%ile				Mean			
	C	B	A	r^2	C	B	A	r^2
Peak SPL_B	3006.3	171.0	0.432	0.83	6141.8	209.9	0.062	0.80
Peak SPL_C	67.7	124.9	0.452	0.34	163.8	127.6	0.301	0.46
Peak SPL_D	48.0	125.2	0.374	0.64	178.9	130.2	0.266	0.87
SEL_U	3137.1	204.4	0.056	0.38	1502.1	184.3	0.047	0.53
SEL_A	4934.9	171.1	0.131	0.84	5460.3	184.4	0.073	0.92
SEL_P	3792.8	158.4	0.304	0.96	4407.0	176.5	0.088	0.95
SEL_{P_1}	6230.5	160.8	0.286	0.82	3214.5	178.2	0.070	0.84
SEL_{P_2}	389.1	144.5	0.148	0.96	499.7	139.6	0.118	0.99
SEL_R	3896.3	158.5	0.305	0.96	4775.8	177.2	0.089	0.95

Table 17. Nonlinear regression coefficients for Equation (20) and the coefficients of determination (r^2) for the regression of mean PTS measured at the 1, 2, and 4 kHz audiometric test frequencies on the nine hazard indices for subjects exposed to 10 (n=282) and 100 impulses (n=444).

90%ile

	C	B	A	r^2
Peak SPL_B	72.9	147.0	0.063	0.66
Peak SPL_C	40.2	123.4	0.246	0.43
Peak SPL_D	51.9	126.8	0.171	0.90
SEL_U	49.7	121.4	0.156	0.73
SEL_A	66.7	128.3	0.119	0.90
SEL_P	64.7	130.4	0.132	0.95
SEL_{P_1}	59.5	125.1	0.154	0.92
SEL_{P_2}	63.0	125.3	0.145	0.93
SEL_R	65.5	130.8	0.128	0.96

50%ile

	C	B	A	r^2
Peak SPL_B	855.9	208.6	0.071	0.62
Peak SPL_C	16.5	125.6	0.330	0.30
Peak SPL_D	16.3	129.6	0.181	0.47
SEL_U	59.8	154.4	0.057	0.35
SEL_A	39.8	135.0	0.162	0.79
SEL_P	78.5	147.0	0.113	0.95
SEL_{P_1}	42.4	132.9	0.185	0.77
SEL_{P_2}	43.5	132.1	0.232	0.89
SEL_R	84.7	148.5	0.110	0.94

Mean

	C	B	A	r^2
Peak SPL_B	200.8	201.6	0.045	0.64
Peak SPL_C	17.8	124.4	0.332	0.39
Peak SPL_D	20.6	127.0	0.188	0.70
SEL_U	25.3	125.2	0.120	0.55
SEL_A	38.3	132.7	0.130	0.90
SEL_P	47.1	138.4	0.114	0.96
SEL_{P_1}	36.3	130.2	0.155	0.86
SEL_{P_2}	10.1	121.7	0.268	0.15
SEL_R49.6139.7	0.108	0.95		

Table 18. Nonlinear regression coefficients for Equation (20) and the coefficients of determination (r^2) for the regression of mean percent OHC loss measured at octave-band lengths of the basilar membrane at the locations correlated with the 1, 2, and 4 kHz audiometric test frequencies on the nine hazard indices for subjects exposed to 10 (n=284) and 100 impulses (n=444). The value of C was set to 100 for these regressions.

90%ile

	C	B	A	r^2
Peak SPL_B	100.0	137.2	0.164	0.69
Peak SPL_C		125.8	0.188	0.39
Peak SPL_D		124.7	0.405	0.94
SEL_U		119.7	0.401	0.75
SEL_A		121.4	0.356	0.89
SEL_P		125.2	0.428	0.96
SEL_{P_1}		121.2	0.432	0.92
SEL_{P_2}		120.5	0.553	0.96
SEL_R		125.3	0.432	0.98

50%ile

	C	B	A	r^2
Peak SPL_B	100.0	156.4	0.107	0.45
Peak SPL_C		154.6	0.061	0.18
Peak SPL_D		161.8	0.058	0.23
SEL_U		143.6	0.089	0.37
SEL_A		135.6	0.260	0.81
SEL_P		137.5	0.271	0.94
SEL_{P_1}		133.0	0.241	0.85
SEL_{P_2}		132.8	0.338	0.98
SEL_R		138.1	0.274	0.90

Mean

	C	B	A	r^2
Peak SPL_B	100.0	157.2	0.069	0.58
Peak SPL_C		154.1	0.050	0.29
Peak SPL_D		150.3	0.060	0.62
SEL_U		145.1	0.059	0.53
SEL_A		137.2	0.106	0.85
SEL_P		138.7	0.112	0.93
SEL_{P_1}		135.9	0.102	0.84
SEL_{P_2}		134.1	0.118	0.91
SEL_R		139.0	0.112	0.93

Table 19. Nonlinear regression coefficients for Equation (20) and the coefficients of determination (r^2) for the regression of total OHC loss on the nine hazard indices for subjects exposed to 10 (n=284) and 100 impulses (n=444).

90%ile

	C	B	A	r^2
Peak SPL_B	7407.4	145.8	0.083	0.63
Peak SPL_C	4149.9	124.9	0.359	0.45
Peak SPL_D	6036.3	129.4	0.180	0.90
SEL_U	5862.5	124.8	0.130	0.66
SEL_A	6822.3	127.6	0.155	0.91
SEL_P	6619.9	129.7	0.188	0.93
SEL_{P_1}	6695.1	127.3	0.171	0.94
SEL_{P_2}	6595.2	125.9	0.179	0.95
SEL_R	6567.2	129.9	0.201	0.94

50%ile

	C	B	A	r^2
Peak SPL_B	90844.6	202.0	0.081	0.62
Peak SPL_C	1721.1	128.2	0.267	0.26
Peak SPL_D	1701.3	132.0	0.205	0.47
SEL_U	63724.6	194.6	0.064	0.44
SEL_A	6941.5	140.9	0.163	0.87
SEL_P	6941.5	140.9	0.163	0.87
SEL_{P_1}	7807.8	144.5	0.153	0.96
SEL_{P_2}	4816.9	135.2	0.176	0.80
SEL_R	5836.8	136.1	0.197	0.98

Mean

	C	B	A	r^2
Peak SPL_B	32141.0	203.8	0.053	0.66
Peak SPL_C	1935.8	125.9	0.282	0.40
Peak SPL_D	2369.2	129.6	0.179	0.77
SEL_U	5236.9	145.0	0.065	0.57
SEL_A	4687.8	135.4	0.129	0.89
SEL_P	5555.2	140.1	0.121	0.96
SEL_{P_1}	4357.1	132.7	0.152	0.90
SEL_{P_2}	4604.7	132.6	0.153	0.95
SEL_R	5728.0	140.9	0.119	0.95

Table 20. Nonlinear regression coefficients for Equation (20) and the coefficients of determination (r^2) for the regression of total IHC loss on the nine hazard indices for subjects exposed to 10 (n=284) and 100 impulses (n=444).

90%ile

	C	B	A	r^2
Peak SPL_B	16698.0	208.5	0.068	0.64
Peak SPL_C	450.7	131.5	0.142	0.40
Peak SPL_D	524.4	134.0	0.158	0.68
SEL_U	4380.0	182.0	0.055	0.57
SEL_A	1361.4	143.6	0.112	0.89
SEL_P	24003.3	188.4	0.083	0.90
SEL_{P_1}	2196.2	151.9	0.093	0.89
SEL_{P_2}	1126.4	137.9	0.144	0.91
SEL_R	23041.0	187.3	0.084	0.91

50%ile

	C	B	A	r^2
Peak SPL_B	4009.3	173.7	0.303	0.83
Peak SPL_C	50.4	125.0	0.281	0.20
Peak SPL_D	37.6	124.5	0.252	0.38
SEL_U	5315.0	195.8	0.078	0.46
SEL_A	52624.2	193.4	0.120	0.84
SEL_P	9451.3	168.0	0.184	0.90
SEL_{P_1}	14092.8	176.2	0.141	0.79
SEL_{P_2}	432.6	146.1	0.135	0.94
SEL_R	9227.9	167.7	0.187	0.90

Mean

	C	B	A	r^2
Peak SPL_B	10844.6	203.2	0.090	0.72
Peak SPL_C	152.1	130.1	0.148	0.36
Peak SPL_D	163.5	131.6	0.171	0.67
SEL_U	3343.0	193.6	0.058	0.55
SEL_A	5081.5	178.7	0.083	0.89
SEL_P	3471.8	171.6	0.095	0.94
SEL_{P_1}	2661.1	171.6	0.081	0.87
SEL_{P_2}	570.4	142.8	0.123	0.95
SEL_R	3653.1	172.0	0.096	0.94

Table 21. Legend to the symbols presented in Figure 78 (a-i): $PTS_{1,2,4}$ and Figure 79 (a-i): percent total OHC loss.

Symbol	Exposure stimulus
■	Conventional shock tube, nonreverberant, JASA, v. 90, p. 197-204
●	Fast-acting valve (5"), nonreverberant, JASA, v. 90, p. 197-204
▲	Fast-acting valve (3.5"), nonreverberant, JASA, v. 90, p. 197-204
◆	Spark gap, nonreverberant, SUNY ARL Report. 91-1
◀	Conventional shock tube, reverberant, JASA, v. 100, p. 2247-2257
▶	Fast-acting valve (3.5), reverberant, JASA, v. 100, p. 2247-2257
◇	260 Hz cf Narrow-band Impact, JASA, v. 93, p. 2860-2869
△	775 Hz cf Narrow-band Impact, JASA, v. 93, p. 2860-2869
○	1025 Hz cf Narrow-band Impact, JASA, v. 93, p. 2860-2869
□	1350 Hz cf Narrow-band Impact, JASA, v. 93, p. 2860-2869
⊙	2450 Hz cf Narrow-band Impact, JASA, v. 93, p. 2860-2869
▽	3550 Hz cf Narrow-band Impact, JASA, v. 93, p. 2860-2869
✙	2075 Hz cf Narrow-band Impact, JASA, v. 93, p. 2860-2869
◪	290C driver, High peak wave, USAARL Report. 86-7
◩	290C driver, Low peak wave, USAARL Report. 86-7

The exposure stimulus is taken from the Stimulus Table of the `Chin_BOP` CD-ROM data base.

Table 22. Values of offset parameters (Bi) for each stimulus estimated using the nonlinear regression described by Equation (21) with the mean $PTS_{1,2,4}$ as the dependent variable and each of the HIs as the independent variable for subjects exposed to 100 impulses. The average and variance of the parameters is given for all the stimuli, the SUNY stimuli, the USAARL stimuli, and all the stimuli with the SUNY values reduced by 10 dB. The value of C was fixed at 50 dB and the value of A was estimated but held constant across stimuli (columns).

	Hazard Indicators (HIs)								
Stimulus Description	Peak SPL_B	Peak SPL_C	Peak SPL_D	Un-weight	A-weight	P-weight	P_1-weight	P_2-weight	R-weight
Conventional Shock Tube	161.8	154.9	158.3	149.2	140.8	139.3	136.3	135.9	140.1
Fast-acting Valve ST 5"	154.1	141.0	141.0	138.1	137.0	139.5	136.5	135.4	139.5
Fast-acting Valve ST 3.5"	149.2	136.2	136.0	133.6	132.5	135.0	131.9	131.0	134.9
Spark Gap	150.3	138.5	140.6	134.0	133.2	138.6	131.6	131.6	138.8
Reverb. Conven. ST	163.7	154.0	152.8	151.2	144.3	146.1	143.9	142.9	146.8
Reverb. FAV 3.5"	154.4	132.9	134.0	135.0	135.3	137.6	135.8	134.4	137.7
260 Hz cf NBI	156.7	149.9	152.9	146.3	138.2	129.4	129.2	129.2	129.3
775 Hz cf NBI	144.0	137.4	140.5	133.5	132.2	129.5	129.5	129.5	129.5
1025 Hz cf NBI	138.9	131.9	133.2	128.7	128.9	129.5	129.5	128.5	129.5
1350 Hz cf NBI	136.0	129.4	132.7	126.0	126.7	128.9	128.9	126.2	128.9
2450 Hz cf NBI	141.4	135.6	136.1	131.4	132.7	131.7	131.6	131.6	135.0
3550 Hz cf NBI	132.9	126.6	127.2	122.8	123.9	130.2	123.0	123.0	128.7
2075 Hz cf NBI	142.6	136.3	138.9	131.7	132.9	131.5	131.8	131.8	131.5
290C driver, High Peak	138.4	129.0	130.1	125.2	125.9	126.8	126.5	125.0	127.9
290C driver, Low Peak	137.4	131.1	136.0	126.8	127.4	128.4	128.1	126.5	129.4
Average	146.8	137.6	139.4	134.2	132.8	133.5	131.6	130.8	133.8
Variance	94.3	78.3	78.9	75.5	32.8	30.9	25.0	25.3	32.2
SUNY Average	155.6	142.9	143.8	140.2	137.2	139.3	136.0	135.2	139.6
SUNY Variance	35.4	86.7	93.1	63.1	21.1	13.5	19.7	18.4	15.7
USAARL Average	140.9	134.1	136.4	130.3	129.9	129.5	128.7	127.9	130.0
USAARL Variance	46.5	48.3	55.4	48.1	20.1	2.3	7.2	8.9	4.5
Adjusted Average	142.8	133.6	135.4	130.2	128.8	129.5	127.6	126.8	129.8
Adjusted Variance	44.8	58.9	66.7	50.0	20.8	6.2	12.9	13.5	8.2

Table 23. Values of offset parameters (Bi) for each stimulus estimated using the nonlinear regression described by Equation (21) with the 90%ile $PTS_{1,2,4}$ as the dependent variable and each of the HIs as the independent variable for subjects exposed to 100 impulses. The average and variance of the parameters is given for all the stimuli, the SUNY stimuli, the USAARL stimuli, and all the stimuli with the SUNY values reduced by 10 dB. The value of C was fixed at 70 dB and the value of A was estimated but held constant across stimuli (columns).

	Hazard Indicators (HIs)								
Stimulus Description	Peak SPL_B	Peak SPL_C	Peak SPL_D	Un-weight	A-weight	P-weight	P_1-weight	P_2-weight	R-weight
Conven. Shock Tube	158.6	149.1	152.7	145.8	137.5	135.5	133.1	132.6	136.4
Fast-acting Valve ST 5"	148.0	134.9	135.0	132.6	131.7	134.1	131.3	130.2	134.3
Fast-acting Valve ST 3.5"	144.8	131.3	131.4	129.6	128.5	131.0	127.9	127.0	131.0
Spark Gap	147.3	134.9	137.1	130.7	129.7	135.1	128.0	127.9	135.2
Reverb. Conven. ST	159.9	149.9	148.5	147.3	139.7	141.8	138.9	138.2	142.7
Reverb. FAV 3.5"	146.3	123.8	123.1	127.7	127.9	129.7	128.2	126.9	129.9
260 Hz cf NBI	151.7	145.0	148.2	141.4	133.4	124.6	124.5	124.5	124.6
775 Hz cf NBI	143.5	137.2	140.4	133.0	131.8	129.2	129.1	129.1	129.2
1025 Hz cf NBI	137.3	130.3	131.6	127.2	127.4	128.0	128.0	127.0	128.0
1350 Hz cf NBI	135.3	128.6	131.9	125.3	126.0	128.2	128.2	125.5	128.2
2450 Hz cf NBI	136.8	130.8	132.0	126.8	128.1	127.1	127.0	127.0	130.4
3550 Hz cf NBI	132.2	126.0	126.6	122.1	123.2	129.6	122.3	122.3	128.0
2075 Hz cf NBI	139.8	133.5	136.2	128.9	130.2	128.8	129.1	129.1	128.8
290C driver, High Peak	138.4	129.3	130.4	125.1	125.8	126.8	126.5	125.0	127.9
290C driver, Low Peak	136.4	130.2	135.2	125.8	126.4	127.4	127.1	125.5	128.5
Average	143.7	134.3	136.0	131.3	129.8	130.4	128.6	127.9	130.9
Variance	69.7	62.6	68.9	58.5	19.8	19.5	14.3	14.5	20.5
SUNY Average	150.8	137.3	138.0	135.6	132.5	134.5	131.2	130.5	134.9
SUNY Variance	43.7	105.6	120.5	74.4	24.4	17.9	18.5	19.1	20.8
USAARL Average	139.0	132.3	134.7	128.4	128.0	127.7	126.9	126.1	128.2
USAARL Variance	32.1	32.4	40.6	32.7	10.3	2.3	4.9	4.8	2.5
Adjusted Average	139.7	130.3	132.0	127.3	125.8	126.4	124.6	123.9	126.9
Adjusted Variance	34.7	62.7	78.0	47.2	22.5	10.3	17.5	17.8	11.6

Table 24. Values of offset parameters (Bi) for each stimulus estimated using the nonlinear regression described by Equation (21) with the mean $PTS_{1,2,4}$ as the dependent variable and each of the HIs as the independent variable for subjects exposed to 10 impulses. The average and variance of the parameters is given for all the stimuli, the SUNY stimuli, the USAARL stimuli, and all the stimuli with the SUNY values reduced by 10 dB. The value of C was fixed at 50 dB and the value of A was estimated but held constant across stimuli (columns).

	Hazard Indicators (HIs)								
Stimulus Description	Peak SPL_B	Peak SPL_C	Peak SPL_D	Un-weight	A-weight	P-weight	P_1-weight	P_2-weight	R-weight
Conven. Shock Tube	167.5	158.1	158.6	149.7	140.0	138.5	135.3	135.0	139.3
Fast-acting Valve ST 5"	153.6	137.1	135.8	132.5	130.8	133.2	130.1	129.2	133.3
Fast-acting Valve ST 3.5"	154.3	137.9	136.2	133.1	131.3	133.7	130.4	129.6	133.7
Spark Gap	158.1	144.8	143.9	136.3	134.3	139.6	132.4	132.5	139.8
Reverb. Conven. ST	165.6	153.1	149.7	147.9	140.0	141.7	139.4	138.5	142.5
Reverb. FAV 3.5"	159.7	138.9	134.6	136.9	136.4	138.3	136.8	135.4	138.5
290C driver, High Peak	144.6	131.8	131.4	126.2	126.3	127.1	126.8	125.3	128.3
USAARL Conven. ST	156.4	142.2	146.1	138.1	131.1	130.8	128.8	128.0	131.4
Average	157.5	143.0	142.0	137.6	133.8	135.4	132.5	131.7	135.9
Variance	51.9	76.5	84.8	61.6	23.3	24.6	18.6	19.6	24.1
SUNY Average	159.8	145.0	143.1	139.4	135.5	137.5	134.1	133.4	137.9
SUNY Variance	32.9	77.4	91.3	56.4	16.5	11.4	13.7	13.3	13.3
USAARL Average	150.5	137.0	138.7	132.1	128.7	129.0	127.8	126.7	129.8
USAARL Variance	70.5	53.8	107.6	70.6	11.5	6.9	2.1	3.7	4.8
Adjusted Average	150.0	135.5	134.5	130.1	126.3	127.9	125.0	124.2	128.4
Adjusted Variance	33.7	63.8	87.2	52.0	15.7	9.6	13.0	12.4	11.0

Table 25. Values of offset parameters (Bi) for each stimulus estimated using the nonlinear regression described by Equation (21) with the 90%ile $PTS_{1,2,4}$ as the dependent variable and each of the HIs as the independent variable for subjects exposed to 10 impulses. The average and variance of the parameters is given for all the stimuli, the SUNY stimuli, the USAARL stimuli, and all the stimuli with the SUNY values reduced by 10 dB. The value of C was fixed at 70 dB and the value of A was estimated but held constant across stimuli (columns).

	Hazard Indicators (HIs)								
Stimulus Description	Peak SPL_B	Peak SPL_C	Peak SPL_D	Un-weight	A-weight	P-weight	P_1-weight	P_2-weight	R-weight
Conven. Shock Tube	160.3	149.4	152.1	142.8	133.9	132.4	129.3	128.9	133.2
Fast-acting Valve ST 5"	149.1	131.8	131.6	128.1	127.0	129.4	126.4	125.4	129.5
Fast-acting Valve ST 3.5"	147.4	129.9	129.6	126.6	125.3	127.8	124.6	123.7	127.7
Spark Gap	150.3	135.3	136.8	128.7	127.4	132.9	125.7	125.7	133.1
Reverb. Conven. ST	161.1	147.7	145.8	143.5	136.0	137.8	135.4	134.5	138.6
Reverb. FAV 3.5"	154.8	131.7	129.5	131.4	131.4	133.6	131.9	130.5	133.7
290C driver, High Peak	138.9	125.0	125.9	120.7	121.2	122.1	121.7	120.3	123.2
USAARL Conven. ST	149.4	133.3	138.4	131.3	124.9	124.6	122.7	121.9	125.1
Average	151.4	135.5	136.2	131.6	128.4	130.1	127.2	126.4	130.5
Variance	52.5	73.6	80.8	61.7	24.9	26.4	21.9	22.4	25.8
SUNY Average	153.8	137.6	137.6	133.5	130.2	132.3	128.9	128.1	132.6
SUNY Variance	34.5	74.9	88.8	58.0	18.3	12.3	17.3	16.2	14.3
USAARL Average	144.2	129.2	132.1	126.0	123.0	123.4	122.2	121.1	124.2
USAARL Variance	54.9	34.1	77.5	56.5	6.7	3.2	0.5	1.3	1.9
Adjusted Average	143.9	128.0	128.7	124.1	120.9	122.6	119.7	118.9	123.0
Adjusted Variance	32.5	58.9	79.0	50.8	15.8	9.5	14.9	13.6	11.0

Table 26. Values of offset parameters (B*i*) for each stimulus estimated using the nonlinear regression described by Equation (21) with the mean total percent OHC loss as the dependent variable and each of the HIs as the independent variable for subjects exposed to 100 impulses. The average and variance of the parameters is given for all the stimuli, the SUNY stimuli, the USAARL stimuli, and all the stimuli with the SUNY values reduced by 10 dB. The value of C was fixed at 100% and the value of A was estimated but held constant across stimuli (columns).

	Hazard Indicators (HIs)								
Stimulus Description	Peak SPL_B	Peak SPL_C	Peak SPL_D	Un-weight	A-weight	P-weight	P_1-weight	P_2-weight	R-weight
Conven. Shock Tube	165.2	157.9	161.0	152.1	143.5	142.2	139.0	138.7	143.0
Fast-acting Valve ST 5"	155.6	142.7	142.6	139.5	138.3	140.7	137.7	136.7	140.8
Fast-acting Valve ST 3.5"	152.6	139.8	139.5	136.8	135.6	138.1	134.9	134.0	138.0
Spark Gap	155.2	144.1	146.1	139.0	138.1	143.6	136.5	136.6	143.8
Reverb. Conven. ST	166.0	156.4	155.3	153.4	146.8	148.5	146.4	145.4	149.1
Reverb. FAV 3.5"	159.6	140.3	139.7	140.6	140.9	143.3	141.3	140.0	143.3
260 Hz cf NBI	159.8	153.4	156.1	149.1	140.9	132.1	131.8	131.9	132.0
775 Hz cf NBI	146.5	140.2	143.1	135.8	134.6	131.9	131.8	131.8	131.9
1025 Hz cf NBI	140.6	133.8	135.1	130.3	130.5	131.1	131.1	130.2	131.1
1350 Hz cf NBI	138.8	132.4	135.5	128.7	129.3	131.5	131.5	128.8	131.5
2450 Hz cf NBI	147.6	142.0	141.8	137.4	138.6	137.7	137.5	137.5	140.9
3550 Hz cf NBI	137.5	131.3	131.9	127.2	128.3	134.6	127.3	127.3	133.0
2075 Hz cf NBI	147.7	141.9	144.1	136.5	137.6	136.3	136.4	136.4	136.2
290C driver, High Peak	141.4	132.1	133.1	128.2	128.8	129.8	129.4	127.9	130.8
290C driver, Low Peak	139.2	132.9	137.8	128.4	129.1	130.0	129.7	128.2	131.1
Average	150.2	141.4	142.8	137.5	136.1	136.8	134.8	134.1	137.1
Variance	94.5	75.4	74.8	73.1	34.0	34.2	26.4	27.6	36.1
SUNY Average	159.0	146.9	147.4	143.6	140.5	142.7	139.3	138.6	143.0
SUNY Variance	30.7	66.2	78.7	52.3	16.6	12.0	16.8	15.5	13.6
USAARL Average	144.3	137.8	139.8	133.5	133.1	132.8	131.8	131.1	133.2
USAARL Variance	49.0	53.5	56.1	50.0	24.1	7.7	10.5	13.7	11.2
Adjusted Average	146.2	137.4	138.8	133.5	132.1	132.8	130.8	130.1	133.1
Adjusted Variance	44.6	54.4	61.8	47.2	21.3	8.7	13.6	15.0	11.2

Table 27. Values of offset parameters (Bi) for each stimulus estimated using the nonlinear regression described by Equation (21) with the 90%ile total percent OHC loss as the dependent variable and each of the HIs as the independent variable for subjects exposed to 100 impulses. The average and variance of the parameters is given for all the stimuli, the SUNY stimuli, the USAARL stimuli, and all the stimuli with the SUNY values reduced by 10 dB. The value of C was fixed at 100% and the value of A was estimated but held constant across stimuli (columns).

	Hazard Indicators (HIs)								
Stimulus Description	Peak SPL_B	Peak SPL_C	Peak SPL_D	Un-weight	A-weight	P-weight	P_1-weight	P_2-weight	R-weight
Conven. Shock Tube	158.2	150.6	154.4	145.5	137.3	135.3	132.9	132.5	136.3
Fast-acting Valve ST 5"	145.6	132.6	132.9	130.4	129.6	132.1	129.2	128.2	132.2
Fast-acting Valve ST 3.5"	145.7	132.4	132.8	130.3	129.4	131.8	128.8	127.9	131.8
Spark Gap	148.7	136.6	138.9	132.5	131.8	137.2	130.3	130.3	137.4
Reverb. Conven. ST	159.4	149.4	147.9	146.8	139.0	141.1	138.1	137.5	142.1
Reverb. FAV 3.5"	151.8	129.3	131.0	132.1	132.5	134.6	133.0	131.6	134.7
260 Hz cf NBI	151.5	144.7	147.4	141.4	133.3	124.5	124.4	124.4	124.5
775 Hz cf NBI	142.6	135.9	138.9	132.0	130.8	128.1	128.1	128.1	128.1
1025 Hz cf NBI	137.3	130.3	131.6	127.1	127.3	127.9	127.9	127.0	127.9
1350 Hz cf NBI	134.7	128.1	131.4	124.7	125.4	127.6	127.6	124.9	127.6
2450 Hz cf NBI	141.5	135.8	135.9	131.6	132.8	131.9	131.7	131.7	135.2
3550 Hz cf NBI	133.8	127.5	128.2	123.7	124.8	131.1	123.9	123.9	129.6
2075 Hz cf NBI	141.3	135.2	137.5	130.6	131.7	130.4	130.6	130.7	130.4
290C driver, High Peak	137.6	128.3	129.3	124.5	125.1	126.1	125.8	124.3	127.2
290C driver, Low Peak	135.7	129.3	134.3	125.1	125.8	126.7	126.4	124.8	127.8
Average	144.4	135.1	136.8	131.9	130.4	131.1	129.3	128.5	131.5
Variance	67.4	56.9	58.2	53.3	18.7	20.7	13.9	15.0	22.8
SUNY Average	151.6	138.5	139.7	136.3	133.3	135.4	132.1	131.3	135.7
SUNY Variance	36.9	85.5	90.6	59.6	16.1	12.1	12.0	12.4	14.5
USAARL Average	139.5	132.8	134.9	129.0	128.6	128.3	127.4	126.6	128.7
USAARL Variance	29.9	31.7	35.2	32.2	12.6	6.0	6.9	8.6	8.6
Adjusted Average	140.4	131.1	132.8	127.9	126.4	127.1	125.3	124.5	127.5
Adjusted Variance	31.3	53.5	59.6	41.6	20.2	9.9	15.5	16.7	12.3

Table 28. Values of offset parameters (B*i*) for each stimulus estimated using the nonlinear regression described by Equation (21) with the mean total percent OHC loss as the dependent variable and each of the HIs as the independent variable for subjects exposed to 10 impulses. The average and variance of the parameters is given for all the stimuli, the SUNY stimuli, the USAARL stimuli, and all the stimuli with the SUNY values reduced by 10 dB. The value of C was fixed at 100% and the value of A was estimated but held constant across stimuli (columns).

	Hazard Indicators (HIs)								
Stimulus Description	Peak SPL_B	Peak SPL_C	Peak SPL_D	Un-weight	A-weight	P-weight	P_1-weight	P_2-weight	R-weight
Conven. Shock Tube	173.2	165.5	164.4	155.4	145.1	143.4	140.2	140.0	144.4
Fast-acting Valve ST 5"	159.3	144.6	142.0	138.1	135.9	138.1	135.0	134.1	138.3
Fast-acting Valve ST 3.5"	160.2	145.7	142.7	139.0	136.6	138.9	135.6	134.7	139.0
Spark Gap	164.9	154.3	151.5	143.4	140.5	145.6	138.4	138.6	146.1
Reverb. Conven. ST	170.9	160.5	155.5	153.3	144.7	146.3	143.9	143.1	147.2
Reverb. FAV 3.5"	164.4	145.8	139.7	142.1	141.0	142.8	141.4	140.0	143.0
290C driver, High Peak	149.2	138.3	136.5	130.9	130.5	131.2	130.8	129.4	132.4
USAARL Conven. ST	165.7	154.4	156.0	147.4	139.4	139.0	136.9	136.2	139.7
Average	163.5	151.1	148.5	143.7	139.2	140.7	137.8	137.0	141.3
Variance	55.6	83.0	95.0	66.0	23.5	24.4	17.0	18.5	23.7
SUNY Average	165.5	152.7	149.3	145.2	140.6	142.5	139.1	138.4	143.0
SUNY Variance	31.4	78.1	92.3	54.5	15.2	11.5	11.9	11.8	13.4
USAARL Average	157.5	146.4	146.3	139.2	134.9	135.1	133.8	132.8	136.0
USAARL Variance	136.2	129.7	190.0	134.7	39.9	30.5	18.5	23.2	26.1
Adjusted Average	156.0	143.6	141.0	136.2	131.7	133.2	130.3	129.5	133.8
Adjusted Variance	42.7	77.2	103.5	61.5	20.5	14.0	16.0	15.9	15.3

Table 29. Values of offset parameters (B*i*) for each stimulus estimated using the nonlinear regression described by Equation (21) with the 90%ile total percent OHC loss as the dependent variable and each of the HIs as the independent variable for subjects exposed to 10 impulses. The average and variance of the parameters is given for all the stimuli, the SUNY stimuli, the USAARL stimuli, and all the stimuli with the SUNY values reduced by 10 dB. The value of C was fixed at 100% and the value of A was estimated but held constant across stimuli (columns).

	Hazard Indicators (HIs)								
Stimulus Description	Peak SPL_B	Peak SPL_C	Peak SPL_D	Un-weight	A-weight	P-weight	P_1-weight	P_2-weight	R-weight
Conven. Shock Tube	161.2	150.7	153.3	143.7	134.6	133.2	129.9	129.6	134.0
Fast-acting Valve ST 5"	149.9	132.5	132.1	128.9	127.6	130.0	127.0	126.0	130.1
Fast-acting Valve ST 3.5"	148.4	130.9	130.4	127.5	126.2	128.6	125.4	124.5	128.6
Spark Gap	151.8	136.8	137.9	130.1	128.8	134.2	127.0	127.0	134.4
Reverb. Conven. ST	161.6	148.0	146.0	144.0	136.5	138.2	135.9	135.0	139.0
Reverb. FAV 3.5"	154.6	131.5	129.4	131.3	131.3	133.5	131.8	130.4	133.6
290C driver, High Peak	138.0	123.9	124.8	119.8	120.3	121.2	120.9	119.4	122.3
USAARL Conven. ST	155.5	140.9	145.3	137.1	130.2	130.0	127.9	127.1	130.5
Average	152.6	136.9	137.4	132.8	129.4	131.1	128.2	127.4	131.6
Variance	57.9	83.5	98.0	69.0	25.4	25.2	19.9	20.9	24.4
SUNY Average	154.6	138.4	138.2	134.2	130.8	133.0	129.5	128.8	133.3
SUNY Variance	32.2	77.1	92.2	56.6	16.6	11.4	15.1	14.3	13.4
USAARL Average	146.7	132.4	135.0	128.4	125.3	125.6	124.4	123.3	126.4
USAARL Variance	152.0	145.2	210.2	149.4	48.5	38.2	24.4	29.7	33.2
Adjusted Average	145.1	129.4	129.9	125.3	121.9	123.6	120.7	119.9	124.1
Adjusted Variance	45.7	79.2	105.8	65.6	23.0	15.1	19.4	18.8	16.4

Table 30. Values of offset parameters (B*i*) for each stimulus estimated using the nonlinear regression described by Equation (21) with the mean percent OHC loss in the cochlea over octave-band lengths of the basilar membrane centered at the locations correlated with the 1, 2, and 4 kHz audiometric test frequencies as the dependent variable and each of the HIs as the independent variable for subjects exposed to 100 impulses. The average and variance of the parameters is given for all the stimuli, the SUNY stimuli, the USAARL stimuli, and all the stimuli with the SUNY values reduced by 10 dB. The value of C was fixed at 100% and the value of A was estimated but held constant across stimuli (columns).

	Hazard Indicators (HIs)								
Stimulus Description	Peak SPL_B	Peak SPL_C	Peak SPL_D	Un-weight	A-weight	P-weight	P_1-weight	P_2-weight	R-weight
Conven. Shock Tube	162.1	154.0	157.2	148.6	140.2	139.0	135.8	135.4	139.8
Fast-acting Valve ST 5"	152.2	139.0	138.9	136.5	135.5	138.0	135.0	134.0	138.1
Fast-acting Valve ST 3.5"	149.0	136.0	135.8	133.5	132.4	134.9	131.8	130.9	134.8
Spark Gap	152.7	141.4	143.6	136.8	136.0	141.6	134.5	134.5	141.8
Reverb. Conven. ST	162.7	152.9	151.6	150.3	143.0	144.9	142.2	141.5	145.7
Reverb. FAV 3.5"	154.8	132.8	134.5	135.2	135.4	137.8	136.0	134.6	137.8
260 Hz cf NBI	157.0	149.9	153.0	146.5	138.3	129.6	129.3	129.4	129.5
775 Hz cf NBI	143.6	136.9	140.1	133.1	131.8	129.2	129.1	129.1	129.1
1025 Hz cf NBI	137.6	130.6	132.0	127.4	127.6	128.2	128.2	127.3	128.2
1350 Hz cf NBI	135.0	128.4	131.7	125.0	125.7	127.9	127.9	125.2	127.9
2450 Hz cf NBI	140.9	135.1	135.6	130.9	132.2	131.2	131.1	131.1	134.5
3550 Hz cf NBI	133.9	127.5	128.2	123.8	124.9	131.2	123.9	123.9	129.6
2075 Hz cf NBI	141.8	135.2	137.8	130.8	132.0	130.7	130.9	130.9	130.7
290C driver, High Peak	137.2	127.7	128.8	124.0	124.7	125.6	125.3	123.8	126.7
290C driver, Low Peak	136.4	129.9	134.9	125.8	126.4	127.4	127.1	125.5	128.4
Average	146.5	137.2	138.9	133.9	132.4	133.1	131.2	130.5	133.5
Variance	98.8	78.5	78.2	76.1	32.9	33.9	23.2	24.7	34.8
SUNY Average	155.6	142.7	143.6	140.1	137.1	139.4	135.9	135.1	139.7
SUNY Variance	31.3	77.8	83.3	53.1	14.4	12.0	11.9	12.1	14.0
USAARL Average	140.4	133.5	135.8	129.7	129.3	129.0	128.1	127.4	129.4
USAARL Variance	49.3	50.4	57.2	50.8	21.1	3.6	5.7	8.3	5.0
Adjusted Average	142.5	133.2	134.9	129.9	128.4	129.1	127.2	126.5	129.5
Adjusted Variance	46.3	56.8	63.7	48.1	18.5	6.4	8.7	10.3	7.8

Table 31. Values of offset parameters (Bi) for each stimulus estimated using the nonlinear regression described by Equation (21) with the 90%ile percent OHC loss in the cochlea over octave-band lengths of the basilar membrane centered at the locations correlated with the 1, 2, and 4 kHz audiometric test frequencies as the dependent variable and each of the HIs as the independent variable for subjects exposed to 100 impulses. The average and variance of the parameters is given for all the stimuli, the SUNY stimuli, the USAARL stimuli, and all the stimuli with the SUNY values reduced by 10 dB. The value of C was fixed at 100% and the value of A was estimated but held constant across stimuli (columns).

	Hazard Indicators (HIs)								
Stimulus Description	Peak SPL_B	Peak SPL_C	Peak SPL_D	Un-weight	A-weight	P-weight	P_1-weight	P_2-weight	R-weight
Conven. Shock Tube	N/A	132.4	N/A	143.1	135.1	132.2	130.5	130.0	133.2
Fast-acting Valve ST 5"	143.6	130.9	N/A	128.5	127.6	130.0	127.2	126.2	130.2
Fast-acting Valve ST 3.5"	143.8	130.7	N/A	128.7	127.7	130.3	127.2	126.3	130.3
Spark Gap	147.4	133.8	135.5	129.8	128.5	133.7	126.6	126.4	133.7
Reverb. Conven. ST	157.5	147.5	145.7	68.3	136.8	139.1	135.9	135.3	140.1
Reverb. FAV 3.5"	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
260 Hz cf NBI	149.8	142.3	145.6	139.6	131.6	122.7	122.7	122.7	122.7
775 Hz cf NBI	141.8	134.8	137.8	131.1	129.9	127.2	127.2	127.2	127.2
1025 Hz cf NBI	134.5	127.6	128.8	124.4	124.6	125.2	125.2	124.3	125.2
1350 Hz cf NBI	132.3	125.6	128.9	122.3	123.0	125.2	125.2	122.5	125.2
2450 Hz cf NBI	135.9	130.1	131.3	125.9	127.2	126.1	126.1	126.1	129.5
3550 Hz cf NBI	129.8	123.6	124.1	119.8	120.9	127.3	120.0	120.0	125.7
2075 Hz cf NBI	136.8	130.1	132.7	125.8	127.1	125.8	126.1	126.1	125.8
290C driver, High Peak	133.7	124.1	125.3	120.5	121.2	122.1	121.8	120.3	123.2
290C driver, Low Peak	133.3	126.8	131.8	122.7	123.4	124.2	124.0	122.4	125.3
Average	140.0	131.5	133.4	123.6	127.5	127.9	126.1	125.4	128.4
Variance	66.2	45.0	52.2	298.4	22.8	21.8	14.8	15.8	23.2
SUNY Average	148.1	135.1	140.6	119.7	131.1	133.1	129.5	128.8	133.5
SUNY Variance	42.6	50.1	51.8	863.5	19.7	13.5	15.3	15.5	16.2
USAARL Average	136.4	129.4	131.8	125.8	125.4	125.1	124.2	123.5	125.5
USAARL Variance	36.3	35.4	43.1	38.2	14.1	3.3	5.5	6.6	4.0
Adjusted Average	136.9	127.9	131.6	120.0	123.9	124.4	122.5	121.8	124.8
Adjusted Variance	35.5	41.9	39.9	353.4	19.3	7.2	13.7	14.3	8.4

Table 32. Values of offset parameters (B*i*) for each stimulus estimated using the nonlinear regression described by Equation (21) with the mean percent OHC loss in the cochlea over octave-band lengths of the basilar membrane centered at the locations correlated with the 1, 2, and 4 kHz audiometric test frequencies as the dependent variable and each of the HIs as the independent variable for subjects exposed to 10 impulses. The average and variance of the parameters is given for all the stimuli, the SUNY stimuli, the USAARL stimuli, and all the stimuli with the SUNY values reduced by 10 dB. The value of C was fixed at 100% and the value of A was estimated but held constant across stimuli (columns).

	Hazard Indicators (HIs)								
Stimulus Description	Peak SPL_B	Peak SPL_C	Peak SPL_D	Un-weight	A-weight	P-weight	P_1-weight	P_2-weight	R-weight
Conven. Shock Tube	165.4	155.9	157.3	147.7	138.2	136.7	133.4	133.1	137.6
Fast-acting Valve ST 5"	151.1	134.1	133.4	130.0	128.6	131.0	127.9	126.9	131.1
Fast-acting Valve ST 3.5"	152.3	135.4	134.4	131.1	129.4	131.9	128.6	127.7	131.9
Spark Gap	160.1	147.1	146.4	138.1	136.0	141.3	134.0	134.2	141.7
Reverb. Conven. ST	164.2	151.2	148.3	146.3	138.5	140.2	137.8	136.9	141.1
Reverb. FAV 3.5"	156.9	134.8	131.8	133.7	133.6	135.7	134.0	132.6	135.8
290C driver, High Peak	143.7	130.7	130.5	125.2	125.3	126.1	125.7	124.3	127.3
USAARL Conven. ST	157.9	143.9	147.6	139.3	132.2	131.9	129.8	129.1	132.5
Average	156.4	141.6	141.2	136.4	132.7	134.3	131.4	130.6	134.9
Variance	52.0	84.7	98.3	62.9	22.6	25.9	16.2	18.2	25.5
SUNY Average	158.3	143.1	141.9	137.8	134.1	136.1	132.6	131.9	136.5
SUNY Variance	35.5	91.0	106.1	58.7	18.4	17.8	13.9	14.9	19.8
USAARL Average	150.8	137.3	139.1	132.2	128.8	129.0	127.8	126.7	129.9
USAARL Variance	100.8	86.9	145.3	100.3	23.9	16.9	8.5	11.6	13.6
Adjusted Average	148.9	134.1	133.7	128.9	125.2	126.8	123.9	123.1	127.4
Adjusted Variance	41.0	81.2	107.5	60.4	21.3	16.9	16.8	17.2	18.6

Table 33. Values of offset parameters (B*i*) for each stimulus estimated using the nonlinear regression described by Equation (21) with the 90%ile percent OHC loss in the cochlea over octave-band lengths of the basilar membrane centered at the locations correlated with the 1, 2, and 4 kHz audiometric test frequencies as the dependent variable and each of the HIs as the independent variable for subjects exposed to 10 impulses. The average and variance of the parameters is given for all the stimuli, the SUNY stimuli, the USAARL stimuli, and all the stimuli with the SUNY values reduced by 10 dB. The value of C was fixed at 100% and the value of A was estimated but held constant across stimuli (columns).

	Hazard Indicators (HIs)								
Stimulus Description	Peak SPL_B	Peak SPL_C	Peak SPL_D	Un-weight	A-weight	P-weight	P_1-weight	P_2-weight	R-weight
Conven. Shock Tube	155.9	N/A	N/A	136.4	128.3	127.0	124.1	123.7	127.9
Fast-acting Valve ST 5"	145.1	N/A	N/A	122.3	121.7	124.1	122.7	121.2	124.3
Fast-acting Valve ST 3.5"	139.1	N/A	N/A	120.7	119.6	122.2	118.6	117.8	122.2
Spark Gap	145.1	N/A	N/A	125.7	124.8	130.4	122.8	123.0	130.5
Reverb. Conven. ST	156.6	N/A	N/A	140.1	133.0	134.7	132.1	131.4	135.5
Reverb. FAV 3.5"	152.0	N/A	N/A	125.7	126.2	128.5	127.3	125.8	128.6
290C driver, High Peak	132.8	N/A	N/A	117.1	117.8	118.7	118.1	116.7	119.8
USAARL Conven. ST	151.8	N/A	N/A	132.2	125.9	125.6	124.2	123.3	126.2
Average	147.3	N/A	N/A	127.5	124.7	126.4	123.7	122.9	126.9
Variance	69.9	N/A	N/A	64.1	24.0	24.6	20.5	21.2	24.3
SUNY Average	149.0	N/A	N/A	128.5	125.6	127.8	124.6	123.8	128.2
SUNY Variance	48.7	N/A	N/A	62.6	22.8	20.1	21.4	21.0	22.0
USAARL Average	142.3	N/A	N/A	124.7	121.8	122.2	121.1	120.0	123.0
USAARL Variance	178.8	N/A	N/A	113.5	32.9	23.9	18.4	21.4	20.5
Adjusted Average	139.8	N/A	N/A	120.0	117.2	118.9	116.2	115.4	119.4
Adjusted Variance	62.7	N/A	N/A	69.1	29.3	21.8	27.1	26.2	23.6

Table 34. Average differences between the offset parameters (B*i*) estimated using nonlinear regression for the 100 impulse conditions minus those estimated for the 10 impulse conditions. The values of A for both 100 impulse and 10 impulse conditions were the same. The values of C for mean and 90%ile $PTS_{1,2,4}$ were 50 and 70 dB respectively. The values of C for all percent OHC dependent variables were set at 100%.

	Hazard Indicator				
Type of Difference	A-weight	P-weight	P_1-weight	P_2-weight	R-weight
Mean, $PTS_{1,2,4}$					
SUNY	4.1	4.1	4.2	4.1	4.1
Adjusted Average	5.6	4.2	5.3	5.4	4.2
Mean, Total %OHC Loss					
SUNY	4.1	4.1	4.2	4.1	4.1
Adjusted Average	5.6	4.2	5.4	5.4	4.2
Mean, $\%OHC_{1,2,4}$					
SUNY	5.4	5.3	5.5	5.5	5.4
Adjusted Average	6.5	5.1	6.3	6.4	5.1
90%ile, $PTS_{1,2,4}$					
SUNY	3.0	2.8	2.9	3.0	2.9
Adjusted Average	6.2	4.7	5.9	6.0	4.8
90%ile, Total %OHC Loss					
SUNY	3.7	3.4	3.6	3.7	3.6
Adjusted Average	6.8	5.3	6.5	6.7	5.4
90%ile, $\%OHC_{1,2,4}$					
SUNY	5.5	5.2	5.0	5.1	5.4
Adjusted Average	8.0	6.4	7.5	7.7	6.5